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HUMAN ENGINEERING ANALYSIS OF THE
AUGMENTED FOUR-WHEELS SYSTEM

by

Stephen H. Gates, George Grant and Robert B. King

1 October 1961

HRB-Singer, Inc.
State College, Pennsylvania

Scientific Report No. 1

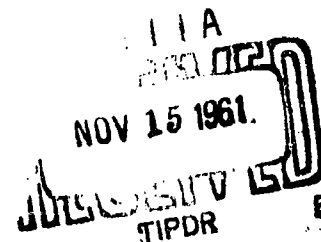
Contract Number AF19(604)-7990

Prepared for

ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH

and

OPERATIONAL APPLICATIONS LABORATORY
DEPUTY FOR TECHNOLOGY
AIR FORCE ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS



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FOREWORD

This scientific report is based on HRB-Singer's first eight months of effort on Contract No. AF 19(604)-7990. The work completed to date has been focused on development of the human engineering requirements for the tower, communications and radar portions of the Augumented "4 Wheels" System. Future efforts will cover the RAPCON, proficiency check-out, and maintenance shelters.

Acknowledgment is made to the assistance and cooperation of James B. Cawley, M/Sgt. Henry Spiewak, SM/Sgt. Richard D. Lewis, and Harvey H. Weiner of the Control Sciences Laboratory. The authors also acknowledge the guidance and cooperation of Dr. John Coules of the Operational Applications Laboratory.

The information included in this report is complete as of 1 October, 1961. Subsequent changes in system design on philosophy will be covered in the final report of this contract.

ABSTRACT

This report is a description of the human engineering aspects of the Precision Approach Radar (PAR), Surveillance Approach Radar (SAR), Communications, and VFR Tower shelters of the Augmented "4 Wheels" System. It describes the layout, equipment configurations, operational functions and ambient conditions for each of these shelters.

The final section outlines human engineering recommendations for common aspects of the system.

TABLE OF CONTENTS

	Page
ASTIA INFORMATION	iii
FOREWORD	v
ABSTRACT	vii
LIST OF ILLUSTRATIONS	xiii
I. SHELTER DESCRIPTIONS	1
A. INTRODUCTION	1
B. COMMUNICATIONS SHELTER	2
1. Shelter Layout	2
2. Teletype Circuit Capabilities	2
3. Number and Function of Operators	18
C. VFR TOWER SHELTER	24
1. Shelter Layout	24
2. Communications Capabilities	29
3. Number and Function of Operators	31
D. SURVEILLANCE RADAR SHELTER	38
1. Shelter Layout	38
2. Communications Capabilities	42
3. Number and Function of Operators	42
E. PAR SHELTER	44
1. Shelter Layout	44
2. Communications Capabilities	44
3. Number and Function of Operators	48

TABLE OF CONTENTS (Cont'd)

	Page
II. AMBIENT CONSIDERATIONS	51
A. INTRODUCTION	51
B. NOISE	52
C. ILLUMINATION	52
D. AIR TEMPERATURE, HUMIDITY, AND VELOCITY	53
III. COMMON DESIGN CRITERIA	55
A. INTRODUCTION	55
B. GENERAL CONSIDERATIONS	56
1. Standardization	56
2. Fail-Safe Design	56
3. Designation of Functional Areas	56
4. Fail-Safe Operation	56
C. LABELING	57
1. Controls and Displays	57
2. Units	58
D. DISPLAYS	58
1. Cathode Ray Tubes	58
E. CONTROLS	60
1. Use of Controls	60
2. Prevention of Accidental Activation	60
F. MAINTAINABILITY	61
1. Unitization of Equipment and Functions	61
2. Location of Components	62
3. Size and Weight of Units	63
4. Attachment of Components	63

TABLE OF CONTENTS (Cont'd)

	Page
5. Rests and Stands	64
6. Covers and Cases	64
7. Lubrication	65
8. Mounting of Units	65
G. ACCESSIBILITY	66
1. General Access	66
2. Apertures	68
3. Interposition	68
H. CONDUCTORS, CONNECTORS, AND FASTENERS	69
1. Conductors	69
2. Connectors	70
3. Fasteners and Mounting Bolts	71
J. TEST POINTS	72
1. Primary (Operational) Test Points	72
2. Secondary (Maintenance) Test Points	72
K. EQUIPMENT COLORS	73
1. Shelters and Trailers	73
2. Consoles and Panels	73
L. WORKSPACE CHARACTERISTICS	73
1. Anthropometry	73
2. Standing Operations	74
3. Seated Operations	74
4. Work Surfaces	76
M. HAZARDS AND SAFETY	76
1. General Safety Considerations	76

TABLE OF CONTENTS (Cont'd)

	Page
N. SUPPLEMENTARY DOCUMENTS	78
1. Technical Reports	78
2. Documents	79
3. Publications	79
DISTRIBUTION LIST	81

LIST OF ILLUSTRATIONS

Figure		Page
1	Communications Shelter, Floor Plan	3
2	Communications Shelter, Left Side View	4
3	Communications Shelter, Right Side View	5
4	Crypto Communications Flow Diagram	6
5	Teletype Communications Flow Diagram	7
6	Voice Communications Flow Diagram	8
7	Telephone Communications Flow Diagram	9
8	Composite Communications Flow Diagram	10
9	Teletypewriter Control Panel	12
10	Teletypewriter Capability	19
11	Control Tower Shelter, Floor Plan	25
12	Control Tower Shelter, Left Side View	26
13	Control Tower Shelter, Right Side View	27
14	Control Tower Shelter End View, Showing Typical Visual Angles	28
15	Transceiver Antenna Configuration	30
16	Transmitter Selector Switch Panel	32
17	Control Console Operation Position No. 1	33
18	Control Console Operation Position No. 2	34
19	Control Console Operation Position No. 3	35
20	Surveillance Radar Shelter, Floor Plan	39
21	Surveillance Radar Shelter, Left Side View	40
22	Surveillance Radar Shelter, Right Side View	41
23	PAR (Precision Approach Radar) Shelter, Floor Plan	45
24	PAR (Precision Approach Radar) Shelter, Left Side View	46
25	PAR (Precision Approach Radar) Shelter, Right Side View	47

I. SHELTER DESCRIPTIONS

A. INTRODUCTION

The following section provides a detailed description of the human engineering aspects of the Communications, Tower, Surveillance Approach Radar (SAR), and Precision Approach Radar (PAR) shelters. Each shelter is described in terms of its layout, and the number and functions of operator positions based on equipment operation philosophy.

B. COMMUNICATIONS SHELTER

1. Shelter Layout

In the process of locating all of the equipment necessary to insure communications capabilities, many workspace compromises were required. The provision of adequate operator workspace has been one of the prime human engineering problems in this shelter.

Figures 1, 2, and 3 show the equipment layout, along with the five possible operator positions.

The shelter layout was determined, in part, by the communication flow through the communication center. Figures 4, 5, 6, and 7 show the flow for (1) Encrypted teletype, (2) Teletype (in-the-clear), (3) Voice radio, and (4) Telephone, respectively, while Figure 8 shows a composite flow for all of these functions.

The present layout of equipment offers the best solution to workspace problems. One serious problem remains, however: pull-out space for the KW-26 cryptographic unit shown in Figure 1. The KW-26 unit is 26 inches long, and the pull-out space is 28 inches. The problem is further complicated by the fact that this unit weighs approximately 100 pounds. Current plans call for a dolly to assist in the removal of this unit for maintenance.

Heat problems were also considered in the design of the shelter layout. The equipments generating the most heat (the two KW-26 units and the radio equipment rack) were located across the back wall (opposite wall from the door) to improve the air conditioning efficiency.

All cryptographic messages that are transferred between the communication shelter and the base must be hand carried and routed through position one. This position has therefore been located just inside the van door in order to reduce the personnel traffic inside the van.

2. Teletype Circuit Capability

There are three HF channels in the communications shelter. Each HF channel is divided into four different audio channels, providing a total of twelve audio channels. Since one HF channel (four audio channels) normally serves as

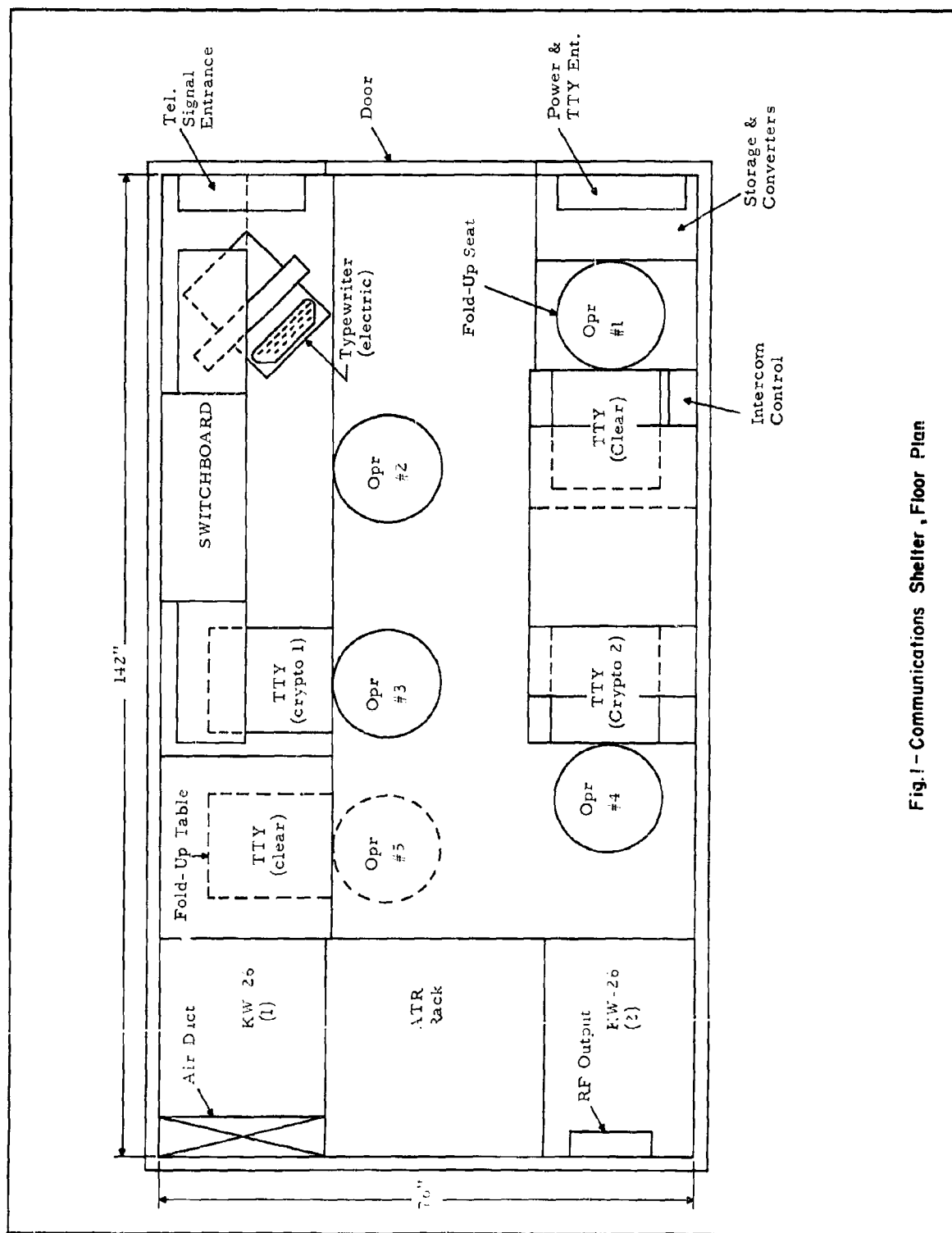


Fig. 1 - Communications Shelter, Floor Plan

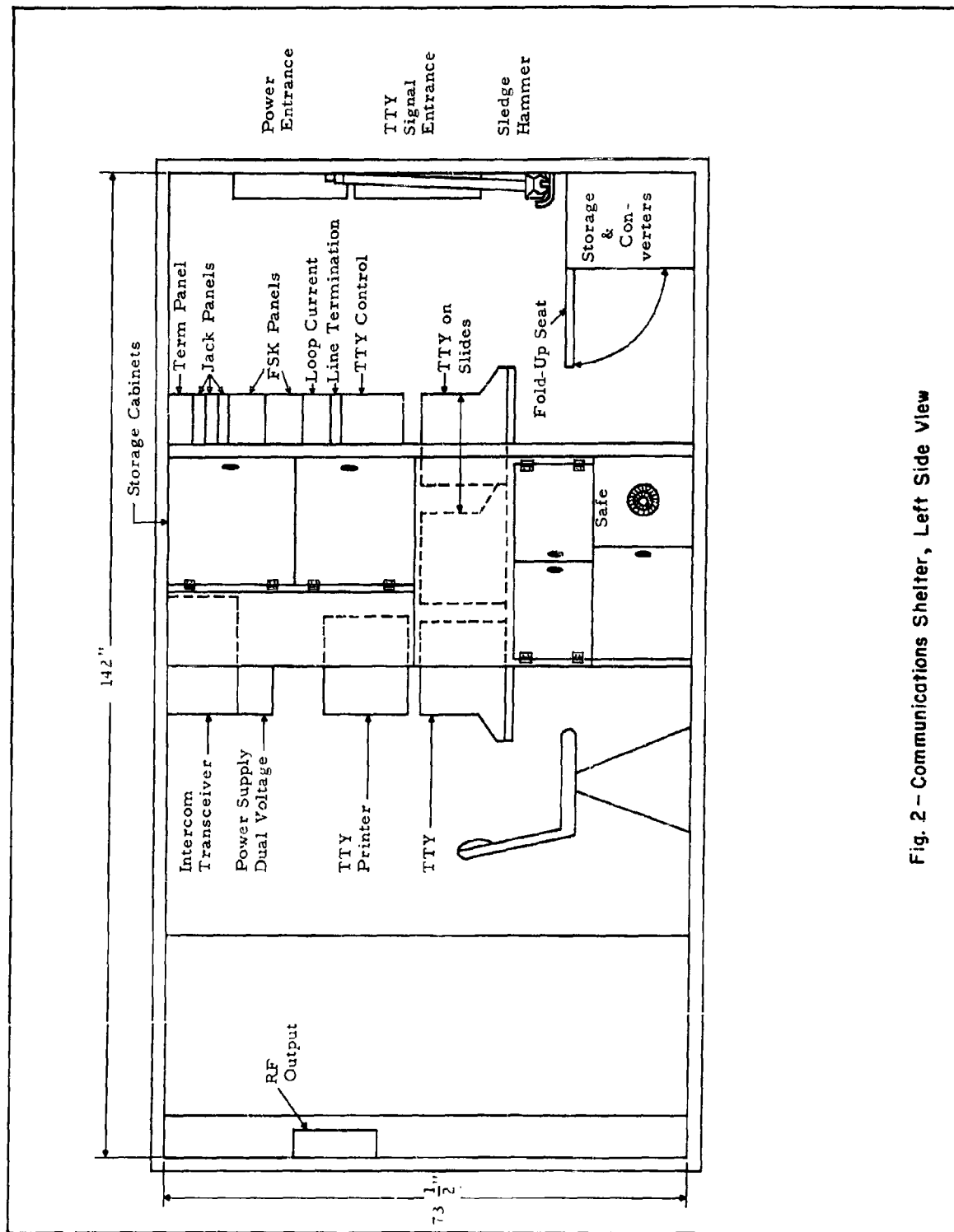


Fig. 2 - Communications Shelter, Left Side View

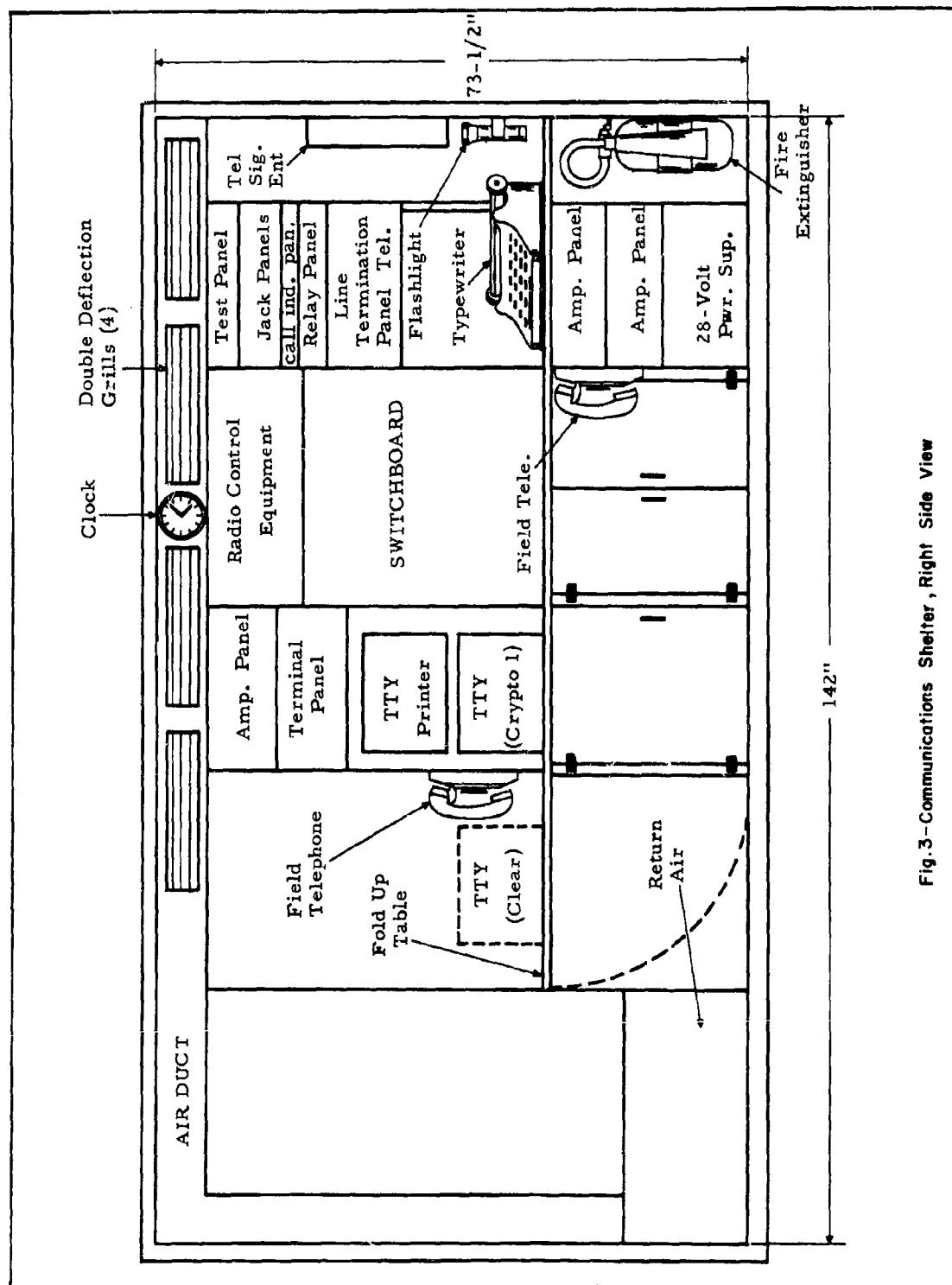


Fig. 3-Communications Shelter, Right Side View

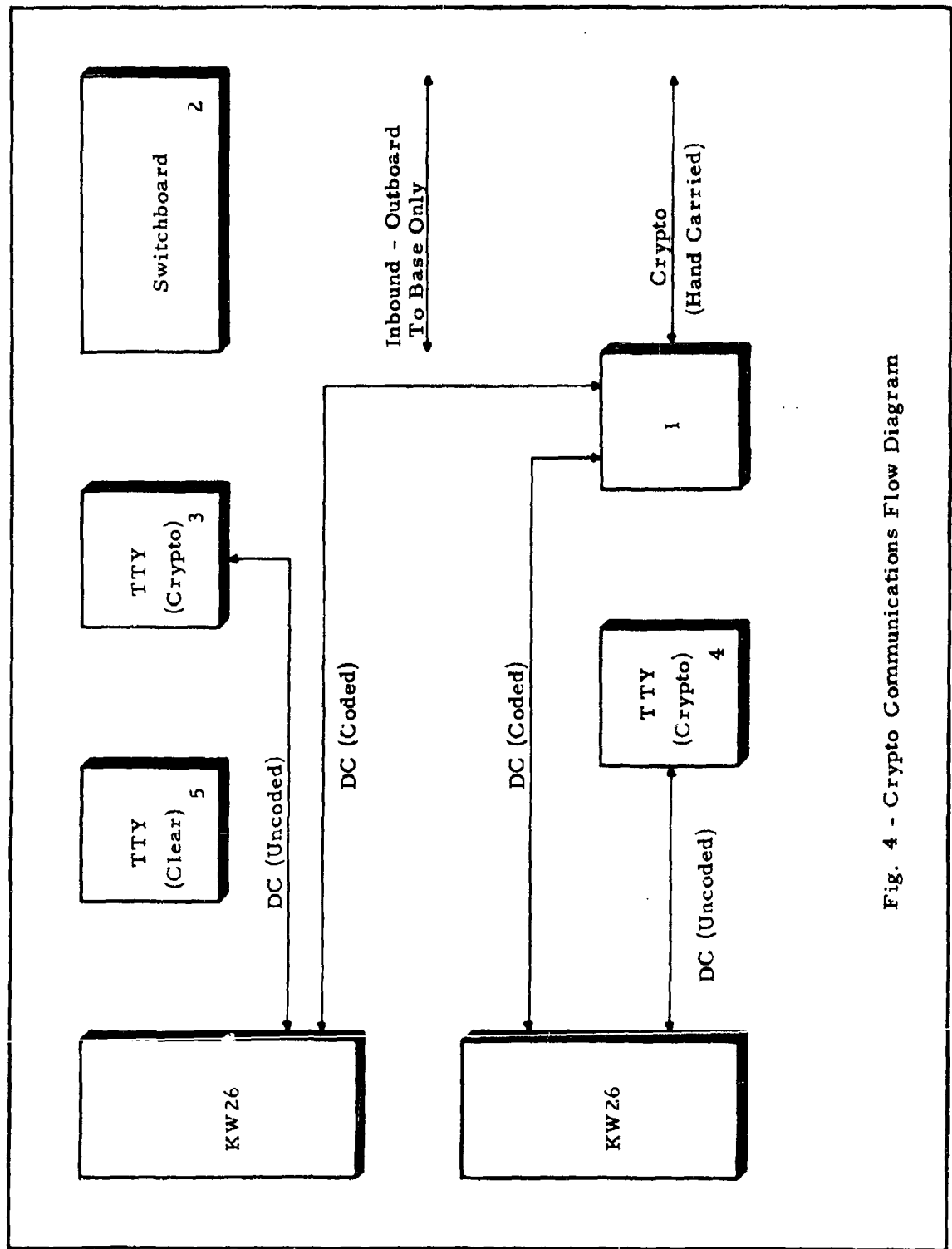


Fig. 4 - Crypto Communications Flow Diagram

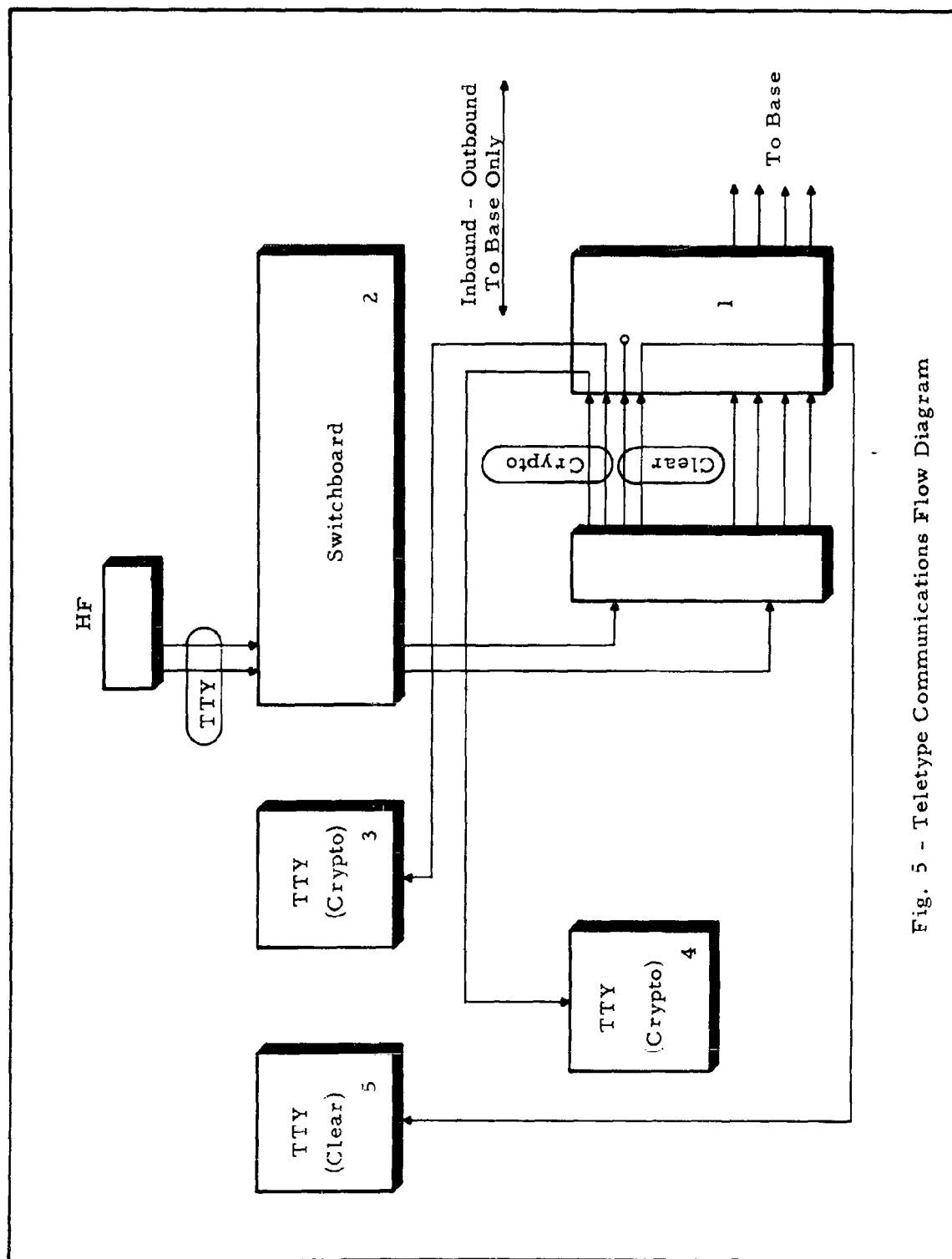


Fig. 5 - Teletype Communications Flow Diagram

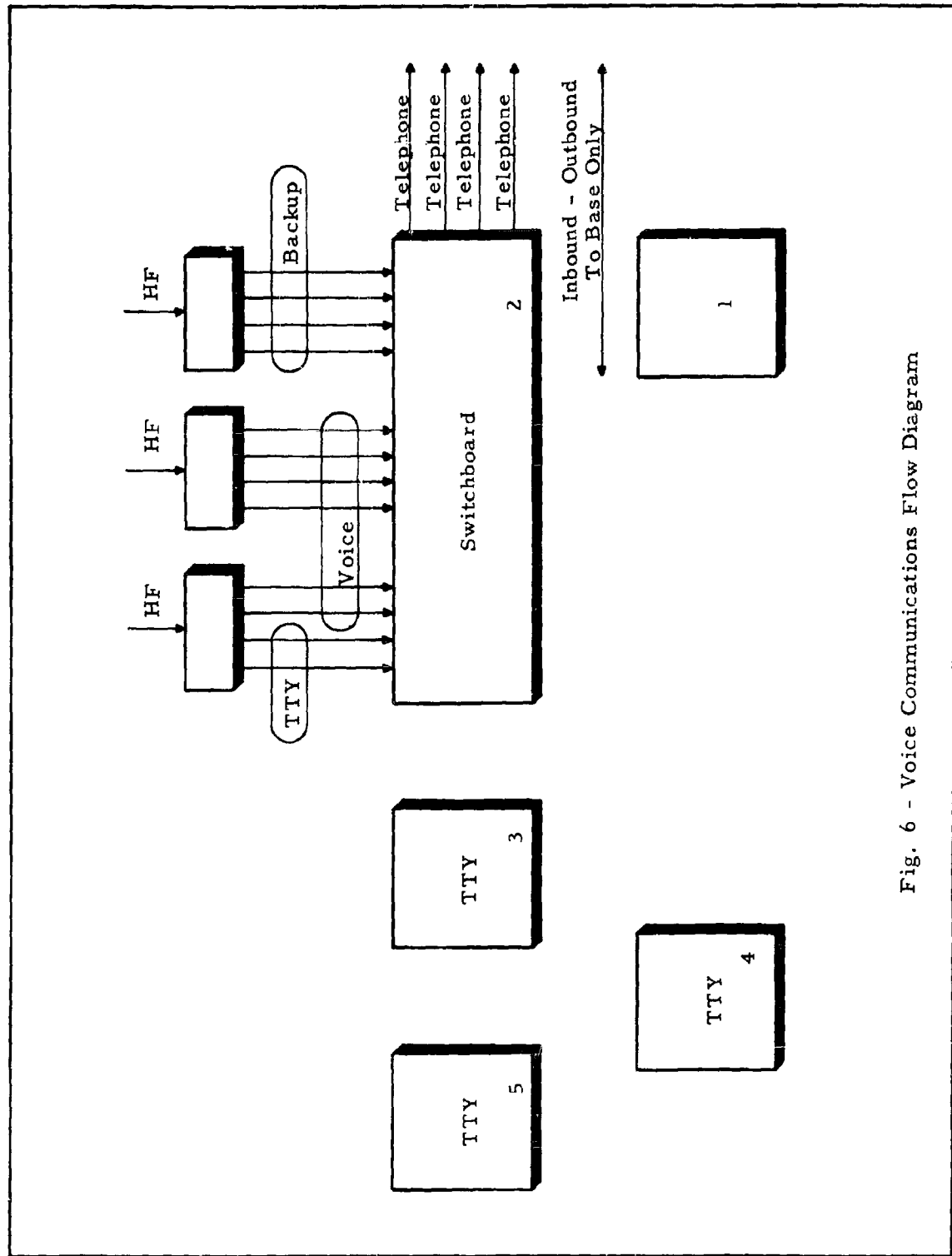


Fig. 6 - Voice Communications Flow Diagram

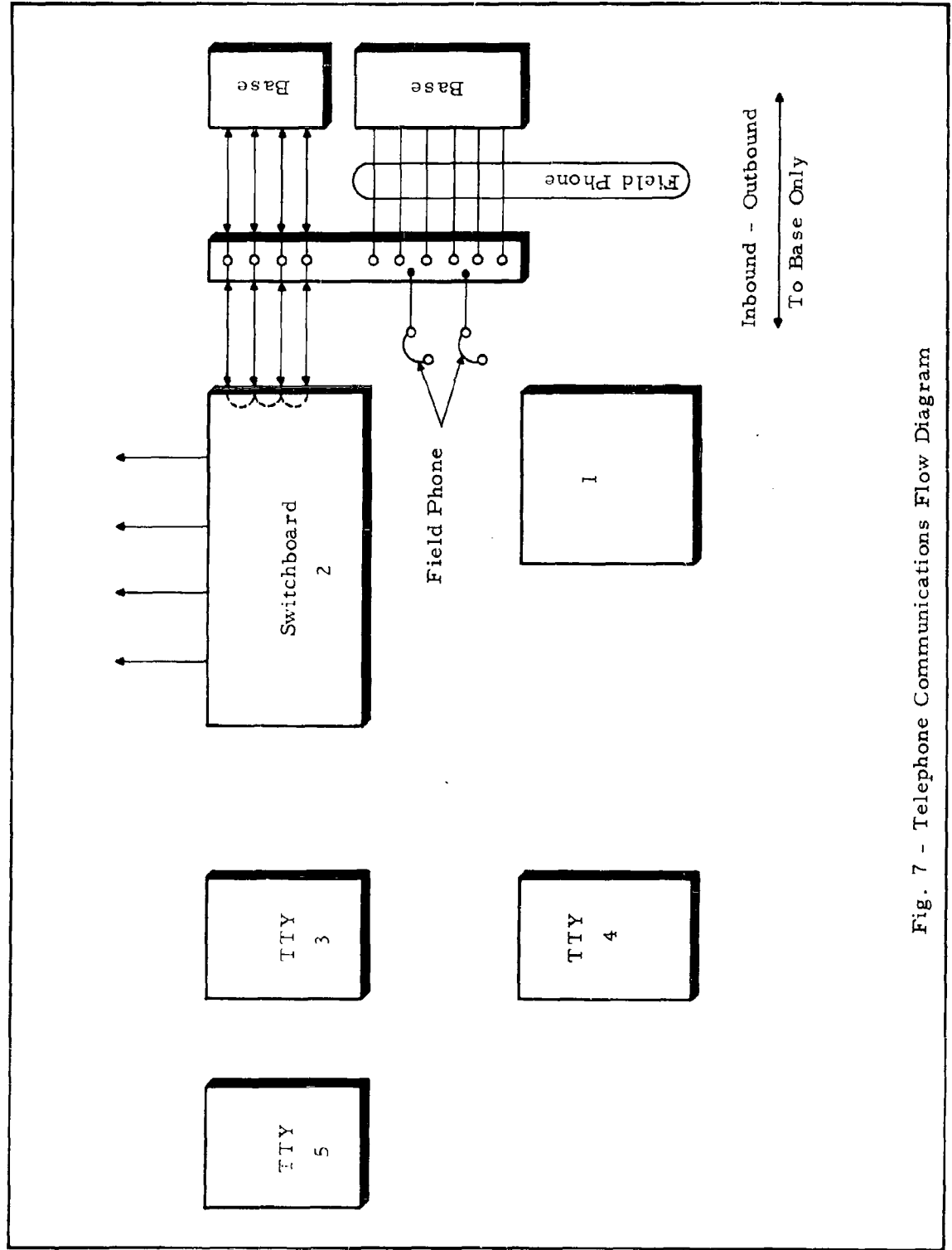


Fig. 7 - Telephone Communications Flow Diagram

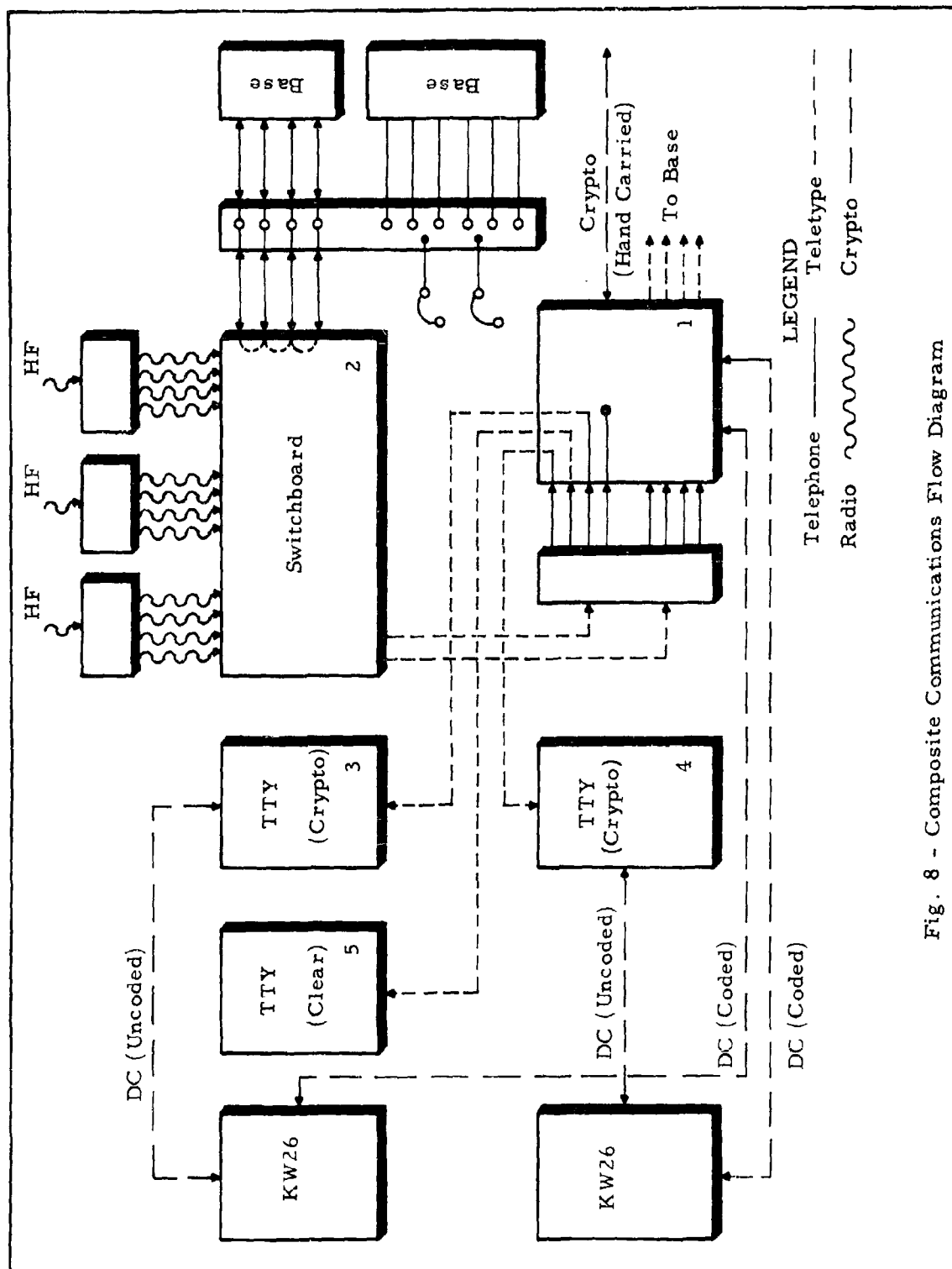


Fig. 8 - Composite Communications Flow Diagram

backup, the operational capability consists of two HF channels (eight audio channels).

Two of these eight audio channels will be required to service the necessary teletype circuits. The other six operational audio channels are assigned to voice communication. In all probability, the two audio channels that are chosen for the teletype function will be split--one audio channel from each of the two operational HF channels. (It will be shown later that this is the optimum selection when diversification, i. e. simultaneous transmission on two or more frequencies, is employed in an attempt to overcome poor transmission conditions).

Each of the two audio channels chosen for the teletype function contains four frequency tones. Each of these eight frequency tones is a possible teletype circuit and goes through FSK (Frequency Shift Keying) equipment that converts audio data to dc data. From here the eight teletypewriter channels are fed through jack fields into the teletype control panel located at operator position number 1.

a. Teletype Control Panel

The teletype control panel shown in Figure 9 is located at operator position number one. It consists of eight columns of controls and indicators, one column for each teletype circuit; four diversity controls, one control for each pair of columns; teletype controls associated with the teletype machine located at this position; a dc loop current meter; and a two-wire or four-wire selector switch.

b. Assignment of Circuits to Control Columns

The assignment of each of the eight teletype circuits to one of the eight control columns (A through H) must be accomplished on the assumption that diversification will sometimes be necessary, depending on transmission conditions. When the transmission on a circuit (A) is diversified, the message is simultaneously transmitted on both circuits A and B, and thus is transmitted with greater power.

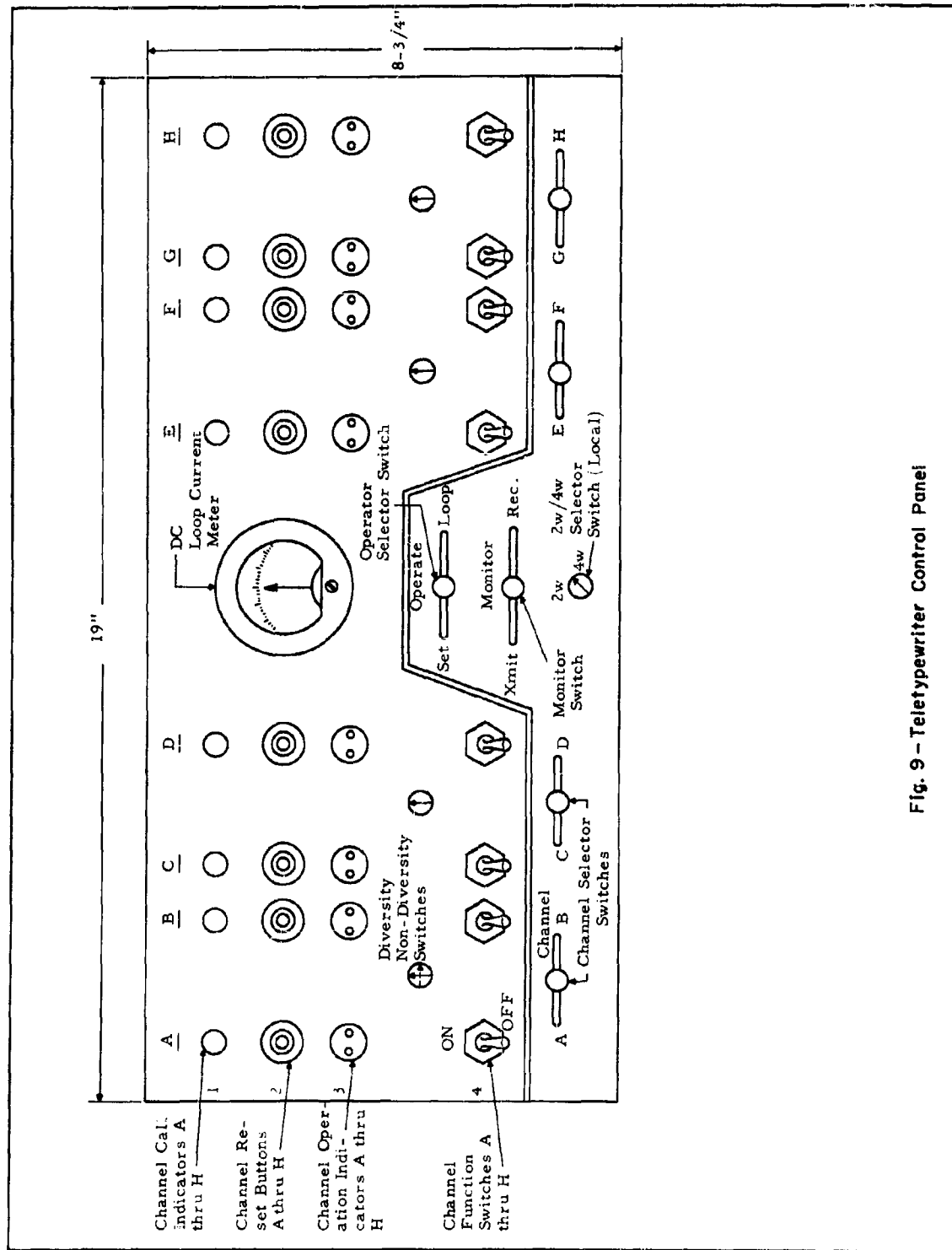
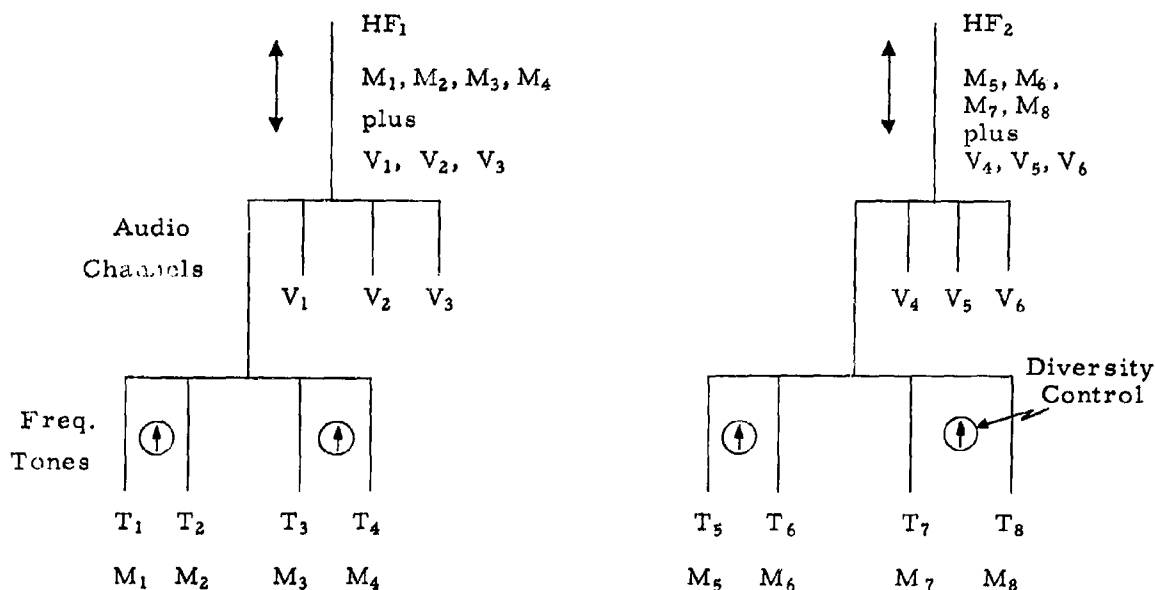


Fig. 9 - Teletypewriter Control Panel

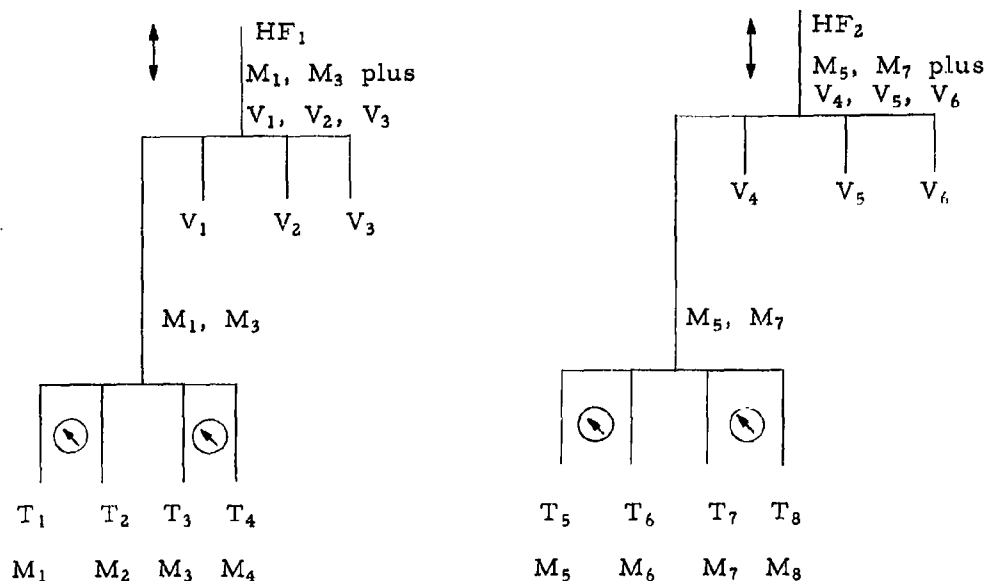
There are four diversity-nondiversity switches, located between control columns A-B, C-D, E-F, and G-H. This is a two-position, on-off switch. The "on" position diversifies the high-priority transmission through both the left and right column frequencies. It should be noted that when a transmission on circuit A, for example, is diversified and transmitted on both A and B, the teletype transmission normally using B is "off the air" for as long as diversification is required. The communications system is thus capable of the following modes of operation.

- (1) Eight nondiversified simultaneous transmissions/receptions. Schematically, this mode looks like this:



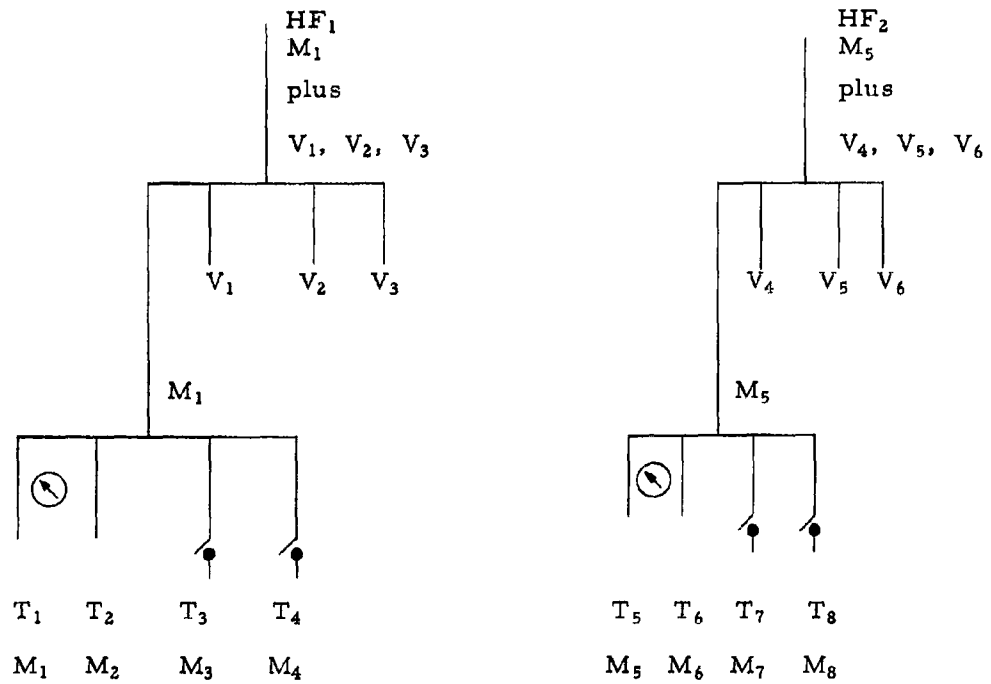
V = voice
T = teletype
M = message

(2) Four simultaneous diversified transmission/receptions.
Schematically:

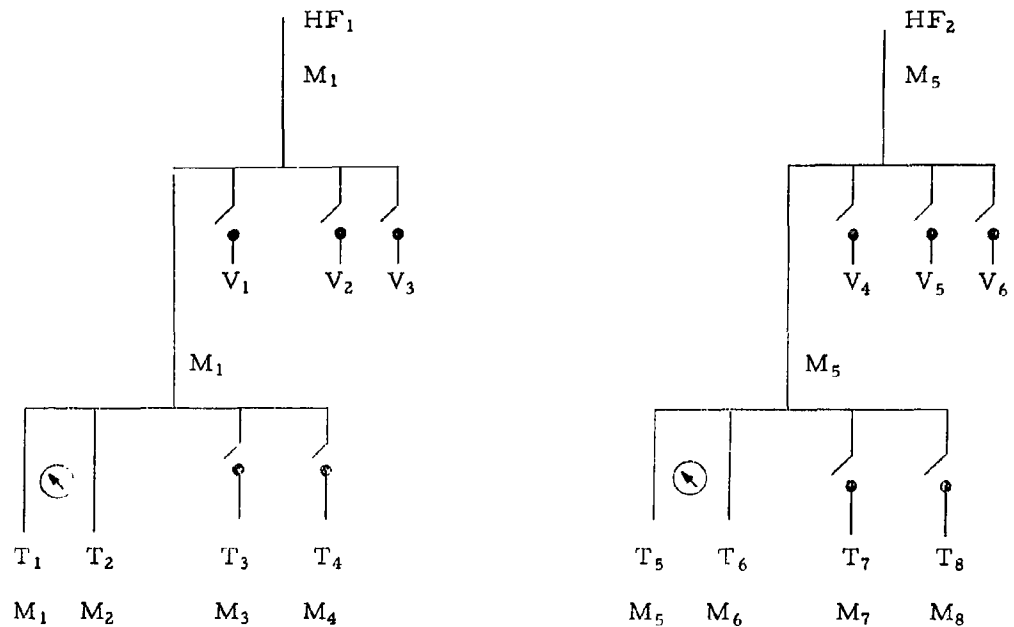


Since the teletype control is flexible, it is possible to achieve further power per transmission/reception. However, to achieve this, the switching must be accomplished between the teletype control panel and the switchboard. Some of these additional switching combinations (multiplexing) include:

- (3) Simultaneous transmission/reception of two separate messages, each message diversified, and each transmitted/received through one of the twelve audio channels. Schematically:



- (4) Simultaneous transmission/reception of two separate messages, each message diversified, and each transmitted/received through two of the twelve audio channels (when the other three audio channels for a given radio are shut down). Schematically, this mode would look like this:



The preceding schematics describe the two extremes in terms of the simultaneous message capacity of the communications shelter. The one end point (maximum number of simultaneous transmissions/receptions) is the condition outlined as number 1 on page 13, while the other (minimum number of simultaneous transmissions/receptions) is diagrammed as number 4. There are many points (control combinations) between these two extremes, as illustrated by schematics 2 and 3.

In general, the relationship is this: as transmission/reception conditions become less favorable, diversification is used to increase the probability of reception. The poorer these conditions become the more diversity and/or multiplexing is required and hence the fewer the number of simultaneous transmissions/receptions, that can be handled by the system. The net effect is a reduction in low-priority circuit capability under unfavorable transmission/reception conditions. (The latter is based on the assumption that as the total number of circuits is reduced through diversity and/or multiplexing, the remaining capability will be reserved for high-priority circuits.)

Considering the above information, the optimum assignment of circuit function to control column is that which maximizes the total number of high-priority transmission circuits under both extremes (when either little or much diversity is required). If we assume that both cryptographic circuits and the one unencrypted circuit are high-priority, we have a total of three high-priority circuits. Let us further assume that there will be a requirement for a high-priority "in-the-clear" circuit which is to be rerouted to a user command headquarters. We now have four high-priority circuits, each of which could be paired with four low-priority circuits. In this manner, circuit diversity can be provided as necessary without reduction in the high-priority transmission/reception capability.

Using this scheme, one cryptographic circuit would be assigned control column A, while the other cryptographic circuit would be assigned control column E. (This would split the cryptographic function, one to each of the two operational HF channels, so that when transmission conditions become poor we could still have two simultaneous cryptographic transmissions).

The two high-priority "in-the-clear" circuits would be assigned control columns C and G. Control columns B, D, F, and H would be assigned to low-priority circuits.

c. Teletype Machine Configuration

Before describing the operations of the teletypewriters, it is necessary to present some background information on the manner in which they are coupled. Each teletype machine includes a keyboard, a punched tape distributor, a page printer, and a tape perforator/writer, and is capable of full duplex operation (i e., each machine can send and receive simultaneously).

It was decided that both the home copy of outgoing crypto messages, and all incoming messages should be in the form of a page printed copy. In order to achieve this format for both home copy and receive copy, it is necessary to couple two teletypewriter machines with each KW-26 unit. Thus, four teletypewriter machines (coupled in pairs) are required to service two KW-26 cryptographic units. One teletypewriter machine per unit is receive only, and the other is send only. This configuration permits both reception and the production of home copy on page printers. Figure 10 outlines the teletypewriter capability in the communication shelter.

3. Number and Function of Operators

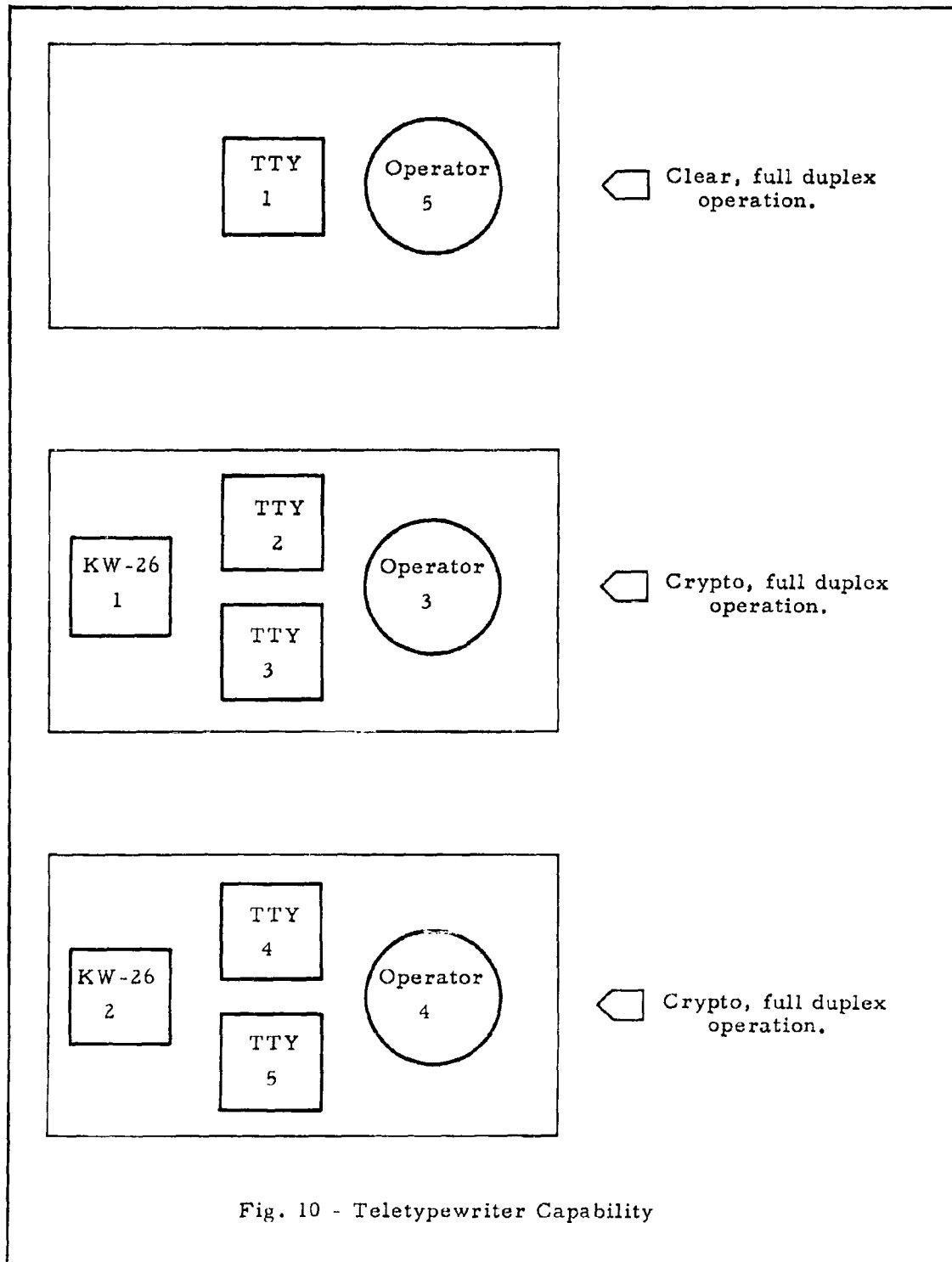
The workspace arrangements and equipment in the Communications Shelter are set up for five operators. The following subsection will include a description of each operating position in terms of the equipment at that position, its capabilities, and the procedures involved in its use.

a. Position One

The operator at position one has control of the teletypewriter circuits. Depending on the type of operation required, he may also have to coordinate some specific control functions with the switchboard (e.g. . . . conditions 3 and 4 on pages 15 and 16).

The controls and indicators incorporated in the Teletypewriter Control Panel permit the operator at position one to: (1) set up as many as eight simultaneous teletypewriter transmissions/receptions, (2) channel up to four simultaneous diversity transmissions/receptions, (3) monitor the transmit or receive side of any teletypewriter circuit, (4) transmit/receive on any eight teletypewriter circuits, (5) monitor the DC loop current, and (6) transmit/receive on local two- or four-wire circuits.

Assuming that there is a requirement for eight teletypewriter circuits, and further assuming that each circuit is assigned a control column on the basis of the rationale previously outlined, the operator at position one performs these functions as follows:



To permit up to eight simultaneous teletypewriter transmissions/receptions, the operator places the Channel Selector Switches (4, A-H, Figure 9) up (to the ON position). This places the eight teletypewriter circuits on the prescribed audio channels for transmission/reception through the radio channels.

To permit up to four simultaneous diversity transmissions/receptions, the operator at position one would move all four of the DIVERSITY-NONDIVERSITY controls to the ON DIVERSITY position.

To monitor the transmit or receive side of any teletypewriter circuit, the operator at position one moves the appropriate Channel Selector Switch to the channel position he desires to monitor and selects either the Transmit or Receive position (whichever is desired) on the Monitor Switch. The material that is being transmitted or received on the monitored machine will be duplicated on the position one machine.

To transmit/receive on any eight teletypewriter circuits, the operator at position one places the appropriate Channel Selector Switch to the desired channel and places the Operator Selector Switch to LOOP (for local transmission/reception) or SET (for radio transmission/reception) [in the latter case, the operator must also move the appropriate Channel Function Switch (4, A-H, Figure 9) to the ON position].

b. Position Two

The primary duty of the operator at position number two is to maintain voice communications between AIRCOM, and the user commands of Augmented "4 Wheels." To a limited extent, he is also responsible for maintaining communications between the user commands via telephone lines, when these are available.

Since all inputs to the communication center come through the switchboard, the operator at this position (in accordance with prescribed policy) must initially set up the two audio channels that are to service the teletype machines. This consists of transferring the two audio channels to the teletype control panel at operator position one and is accomplished by means of normalized jacks if the connection is to be relatively permanent. From this point on, the switchboard operator's duties in regard to the teletype circuits are limited to changing the teletype audio channels or setting up multicoupling when required.

The cordless switchboard is the control link between the audio channels and the telephone circuits. Since there is provision for routing only four of the ten telephone circuits through the switchboard at any given time, and since two of the twelve audio channels are required for the teletypewriters and four audio channels are back-up, the control link at the switchboard is between six audio channels and four telephone circuits. This means that there are four independent patches, each capable of connecting two circuits together (telephone to telephone, telephone to radio, radio to radio). Two separate pairs of connecting circuits may be joined together for a four-way conference. Both operators may then also join in as the fifth and sixth parties.

The six telephone circuits that are not routed through the switchboard may be connected to either of two field phones that are provided.

In addition to patching the six audio channels to the four telephone lines, the operator controls the radio transmitter RF gain, simplex/duplex operation, high/low power, keyline, and AM-SSB-CW operation.

In general, the operator at position two in the communication shelter can call, answer, and control all switchboard circuits--four telephone, six operational audio, and four audio back-up. Some incoming messages, either by intent or due to busy telephone lines, will be terminated in the center (either permanently or temporarily). Messages of this nature must be recorded on the typewriter provided, and will subsequently either be used in the center or sent out on a telephone line when one becomes available. The time-consuming nature of this duty may, on occasion, require this position to be a two-man operation. At such times, the regular operation would be supplemented by one of the other regular operators assigned to the shelter, or by a sixth operator.

c. Positions 3 and 4

Since the equipment of the two cryptographic teletypewriter operators is identical, their operations will be considered together. However, one of these two operators must also perform minor maintenance on the KW-26 units. This will involve changing code cards when required, and synchronizing the KW-26 units when operation is resumed after any power shut-down.

While the receive operation for cryptographic material is rather automated, the send portion of the operation is manual. A previous subsection pointed out that the home copy of all outgoing cryptographic messages should be page printed. This requirement and the capability of the transmitting equipment indicate the following sequence of operations.

After the operator has been given the message to be sent, he will punch a tape of message using the keyboard. This tape contains the desired characters in both perforated and typed form. The typed character appears on the tape just below the perforation. The perforating and typing occur at the extreme right side of the machine, and as the tape passes from right to left approximately one full line of material is exposed. This will provide the operator with positive feedback regarding any errors that might have occurred. If the operator notices an error, he notches the bottom edge of the tape at the location of the error. He continues in this fashion until the message is completed in tape form. This first tape will be called the "error tape" to avoid confusion later in the discussion.

The next step is to place the "error tape" in the distributor which automatically duplicates, in either tape or page printed form (or both), any tape it contains (in this case the "error tape"). Wherever the "error tape" has an error notch, the distributor stops, permitting the operator to correct the error on the new tape. After this operation is completed, we have both an "error tape" and a "corrected tape," and the "error tape" can be destroyed.

The next and final operation is to place the "corrected tape" in the distributor for automatic transmission. As the "corrected tape" is being transmitted by the distributor, a page-printed home copy is simultaneously produced as a record. After the message has been completely transmitted, the "corrected tape" may be destroyed, and the page-printed home copy may be filed.

In reviewing the steps in this operation, it is apparent that a large percentage of the operator's time is involved in PREPARING the message for transmission, rather than in actually transmitting the message. However, once an error has occurred it is impossible to correct on the same tape since it would be mutilated by the excess perforations. If field conditions should prove that this operator's time is critical, it would be worthwhile investigating the

the error rate of experienced operators and the information that is actually lost as a result of these errors. It might be hypothesized that redundancy factors would largely overcome the information loss resulting from errors and that operator time requirements could be reduced (by eliminating the need for preparation of "corrected tapes") without reducing the system effectiveness.

d. Position 5

With the exception of a few minor differences, the equipment at this position is operated in the same fashion as the cryptographic teletype machines. It should be recalled that the unencrypted over-all teletype machine configuration requires one machine less for this function while maintaining a full duplex (See Figure 10). The reason for this, of course, is that the reception is on the page-printed portion of the machine, while the home copy is in the form of a tape generated by the perforator-type portion of the same machine. Other than this difference, the operational steps are the same. That is, the operator generates an "error tape" complete with error notches, runs this "error tape" through the distributor to generate a "corrected tape," and places the corrected tape in the distributor for transmission. The "corrected tape" is retained as the home copy, and reception is in the form of a page-printed copy.

The teletype machine at position 5 as well as the machine at position 1 is for transmitting and receiving "in-the-clear" messages. The two pairs of machines assigned to the two KW-26 units are for transmitting and receiving cryptographic messages ONLY. The frequency and duration of traffic rates for either type of message are not yet known, and therefore no estimate of the relative loads on teletype operators can be made at this time.

C. VFR TOWER SHELTER

1. Shelter Layout

The primary factor in determining the location and configuration of equipments in the tower shelter was the need for external visibility from each operating position.

Figures 11, 12, and 13 show the general configuration, equipment layout, and the three possible operator positions. Figure 14 illustrates operator eye positions and the resulting visual area. Since operator visibility was the major consideration, layout was determined for the most part by anthropometric dimensions. The shelter configuration was designed to permit the operator a 360-degree view of the surrounding area, with a minimum total visual angle of 47 degrees (see Figure 14). Since this particular VFR shelter is intended for use on the ground or at a maximum height of five feet, the upward visual angle, as taken from a horizontal plane at the eye level, is the most critical. Anthropometric measurements of a population representative of personnel who would be expected to operate this facility revealed that the eye level (as measured from the floor in a seated position) of 95% of the population falls below 51 inches. The visual area of the tower was therefore designed to permit a minimum upward visual angle of 30 degrees for 95% of the operating population. As can be seen from Figure 14, as the eye level height of the operator decreases, the upward visual angle increases, with 50% of the population having an upward visual angle of 33 degrees, and 5% having an upward visual angle of 36 degrees. In general then, an average operator, falling at the 50th percentile of the Air Force population, would have a total visual angle of 48 degrees, and an upward visual angle of 33 degrees.

The operator control console was also designed for maximum efficiency in terms of anthropometric data (see Figure 14). The console height is 30 inches, which is the optimum height for 50% of the population of operators. The working surface of the console is 12 inches deep. This dimension was chosen on the basis of the number and function of operator controls, and the nature of other operator tasks such as writing.

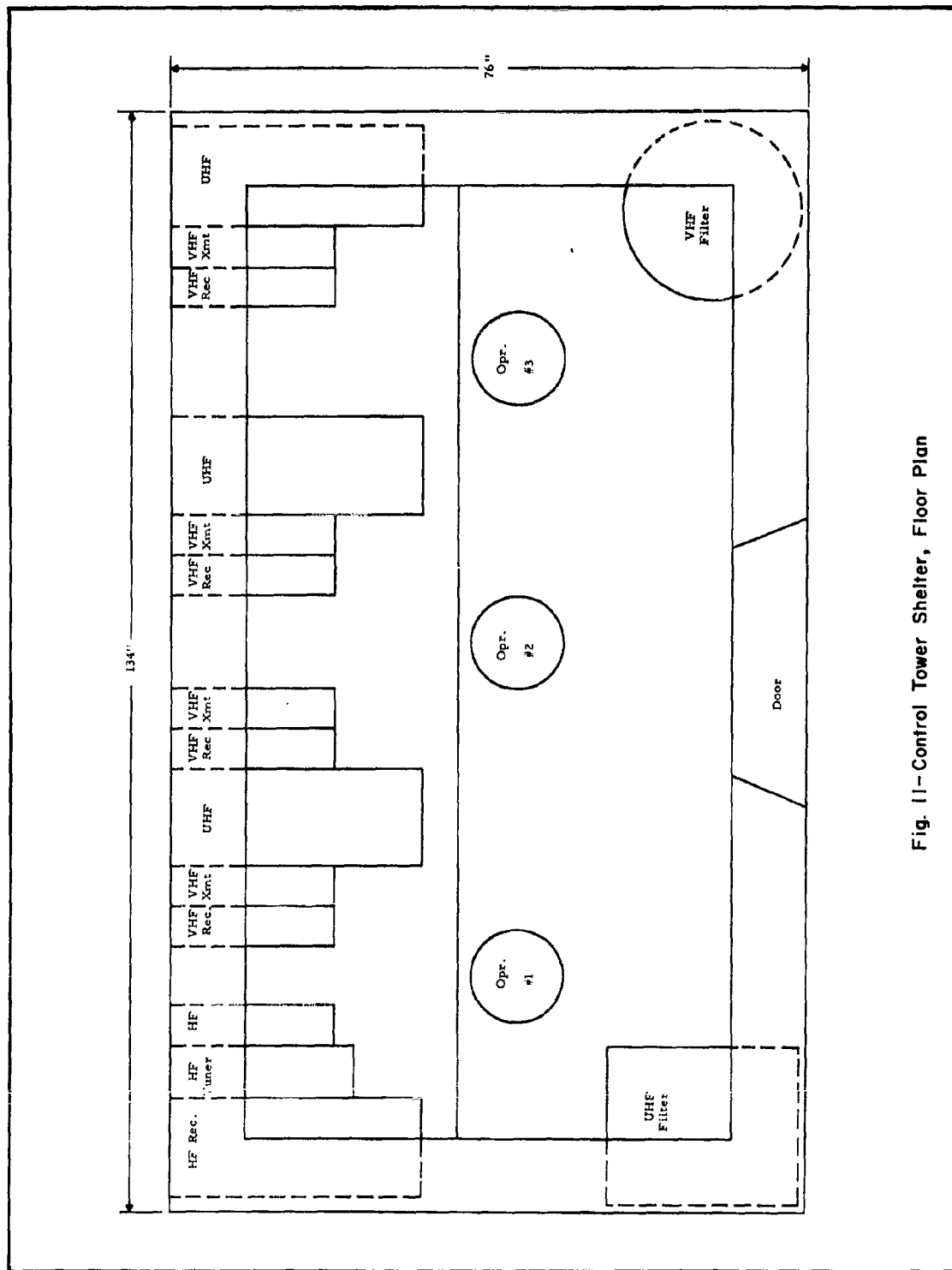


Fig. 11-Control Tower Shelter, Floor Plan

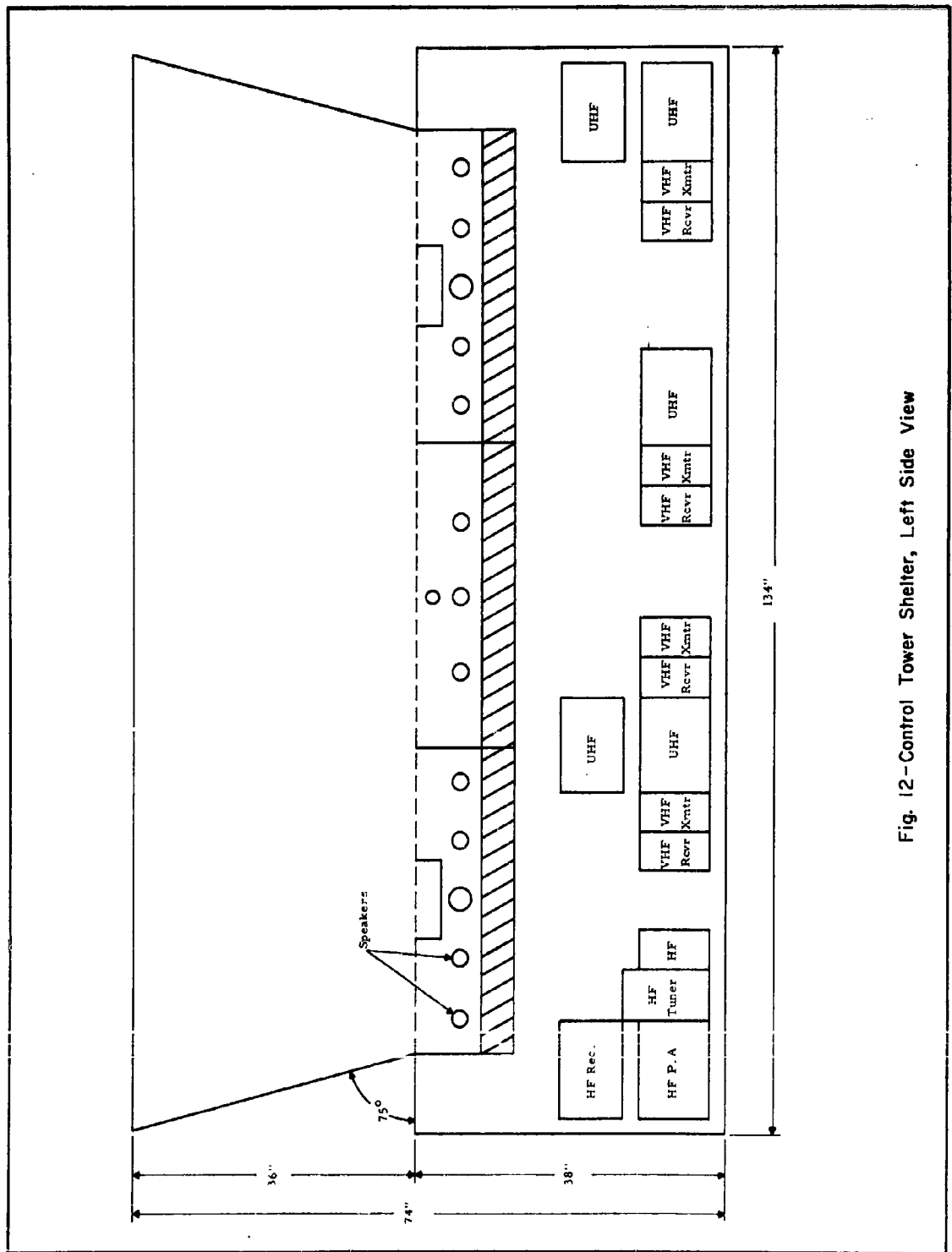


Fig. 12-Control Tower Shelter, Left Side View

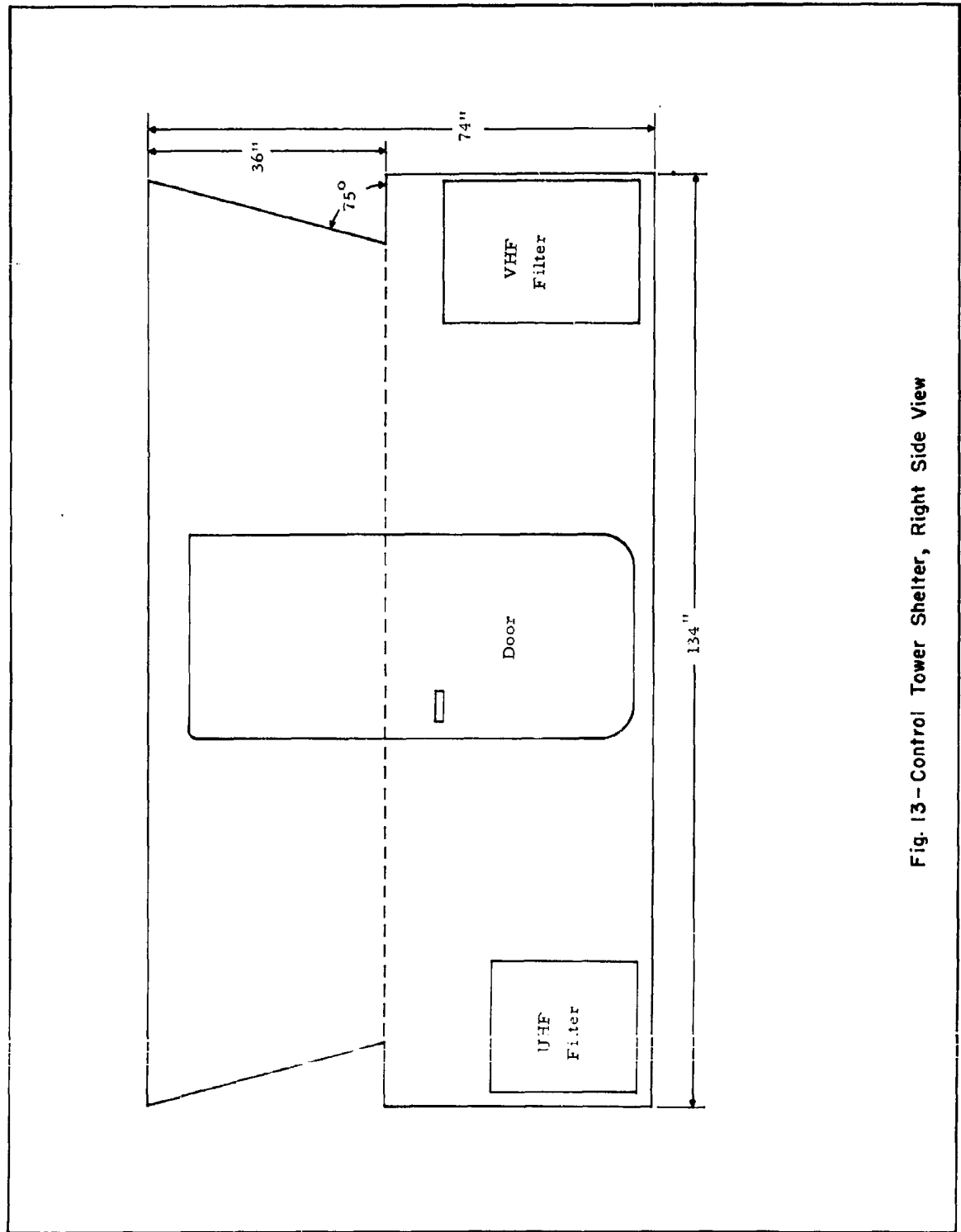


Fig. 13 - Control Tower Shelter, Right Side View

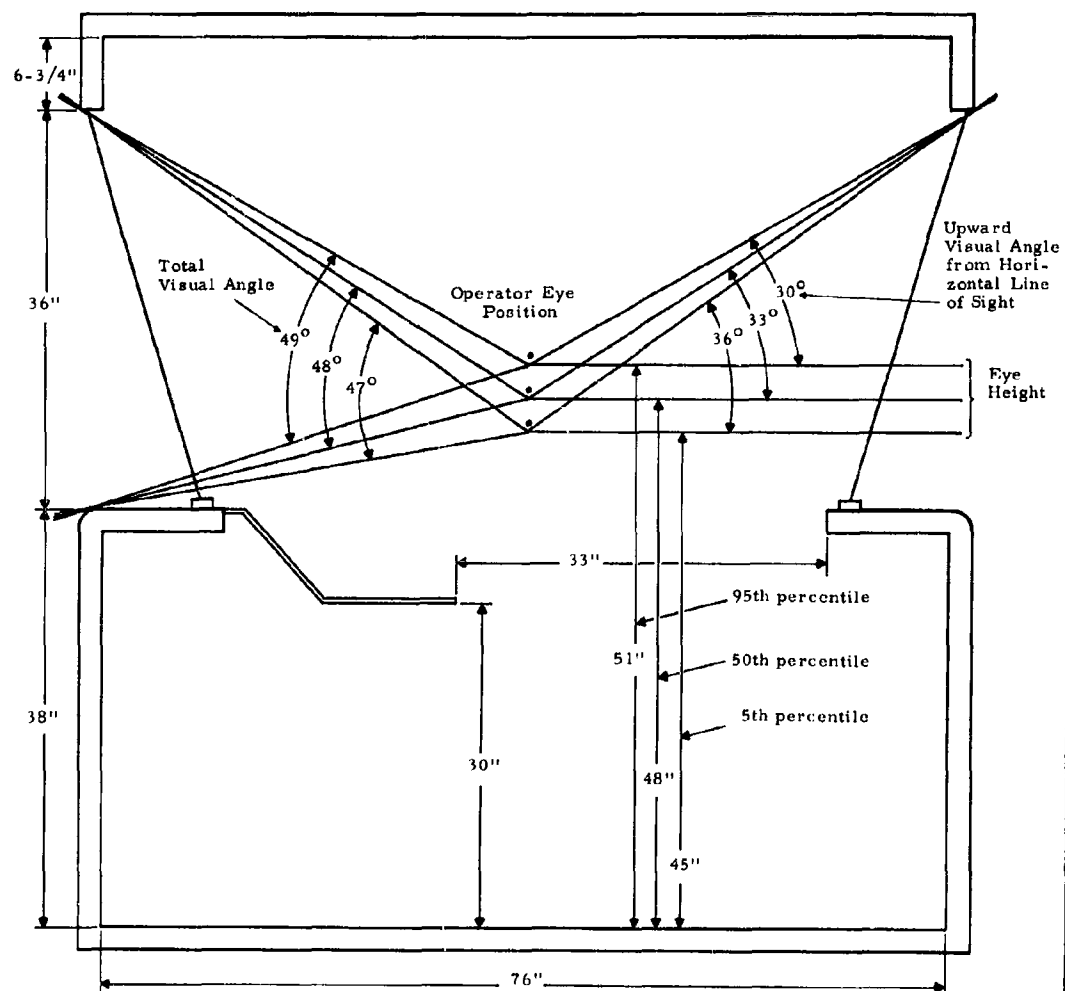


Fig. 14- Control Tower Shelter End View, Showing Typical Visual Angles

In view of the excessive amounts of heat produced by the UHF/VHF transceiving equipment, this equipment was located in the area beneath the control console. The concentration of heat-producing equipment in one area enhances air conditioning efficiency by permitting a substantial reduction in the amount of ductwork required. Accessibility of the transceiving equipment for maintenance was enhanced by hinging the working surface of the control console to swing upward.

Inclement weather and external temperature changes after produce fogging of the internal window surfaces. This problem was resolved by providing air conditioning ductwork sufficient to wash all internal window surfaces with air.

Since auditory communications are vital to the primary functions of this shelter, it will probably be necessary to place a layer of acoustical tile on the ceiling surface to reduce the noise caused by the air conditioning system, other equipments, and the voices of the operators.

During set-up and operation access to the roof of the shelter will be required for antenna installation, adjustment, and maintenance. A 36-inch wide catwalk, surrounding the shelter at the lower edge of the glass area, and a ladder leading from the catwalk to the roof have been recommended for this purpose. During transit the ladder will be removed and the catwalk will fold upward and attach at the top of the glass to act as a protective screen for the glass area.

2. Communications Capabilities

There are five UHF transceivers, four VHF transceivers, and one HF transceiver in the VFR tower shelter, providing a total of ten audio channels.

Figure 15 illustrates the antennas necessary to accommodate the ten transceivers. The coupling of four UHF transceivers to one UHF antenna, and three VHF transceivers to one VHF antenna, permits savings in weight, mounting, maintenance, and storage by reducing the total number of antennas to five -- two UHF, two VHF, and one HF whip. This arrangement, however, necessitates the use of one UHF and one VHF filter.

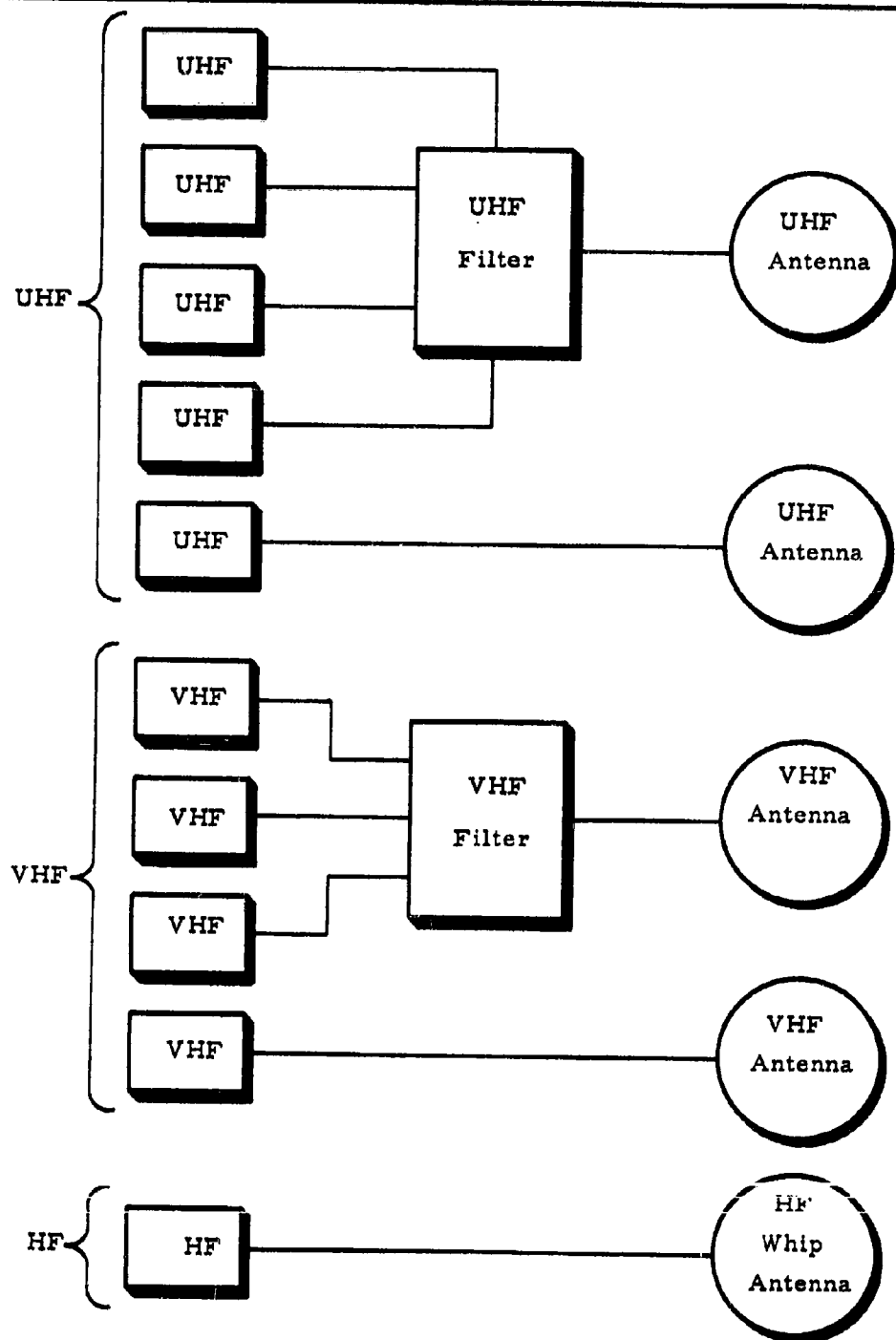


Fig. 15 - Transceiver Antenna Configuration

In addition to the UHF/VHF air-ground-air facilities, inter-shelter communications facilities are included for exchange of information (e.g., landing clearances) with the PAR or IFR shelters, and also for coordination of traffic flow with other agencies.

Direct communications with other units, for relaying flight data, operational messages, time checks, status reports, and weather, will be possible via HF radio communications when other methods are inoperative or temporarily unavailable.

Subsequent discussion of the operator functions will show that one of the operator positions serves as a data position. The presence of this position allows the VFR tower to serve as a limited IFR facility. The VFR tower facility will also contain UHF/VHF DF equipment, which will enable controllers to vector aircraft to the operation location, and to direct instrument let-downs when navigational aids and radars are unavailable.

Figure 16 illustrates the selector switch control panel, which is identical in all three operator positions (see Figures 17, 18, and 19). Each of the transmitter selector switches are three-position switches, the UP position provides reception through speakers in the control console, the DOWN position permits reception through headsets, and the middle position acts as a neutral or monitor position, and also as an OFF position. Operators in each of the three positions have identical, dynamic, push-to-talk microphones, and are able to select any of the ten transmitters. Indicator lights, energized in the UP and DOWN positions, are provided on the selector switch panels to show "IN USE" transmitters, and electronic lock-out circuits, also energized in the UP and DOWN positions, prevent (via relay circuits) operation of a single transmitter by any two operators. The first operator making a channel selection (by placing a particular circuit switch in the UP or DOWN position) disconnects the microphone and key lines of the other two stations from the transmitter circuit which he is using, thereby locking out the other two operators.

3. Number and Function of Operators

The VFR tower shelter contains workspace arrangements and equipments for three operators. Operators in positions one and three have speaker control panels as shown in Figures 17 and 19. The operator in position two has a speaker control panel as shown in Figure 18.

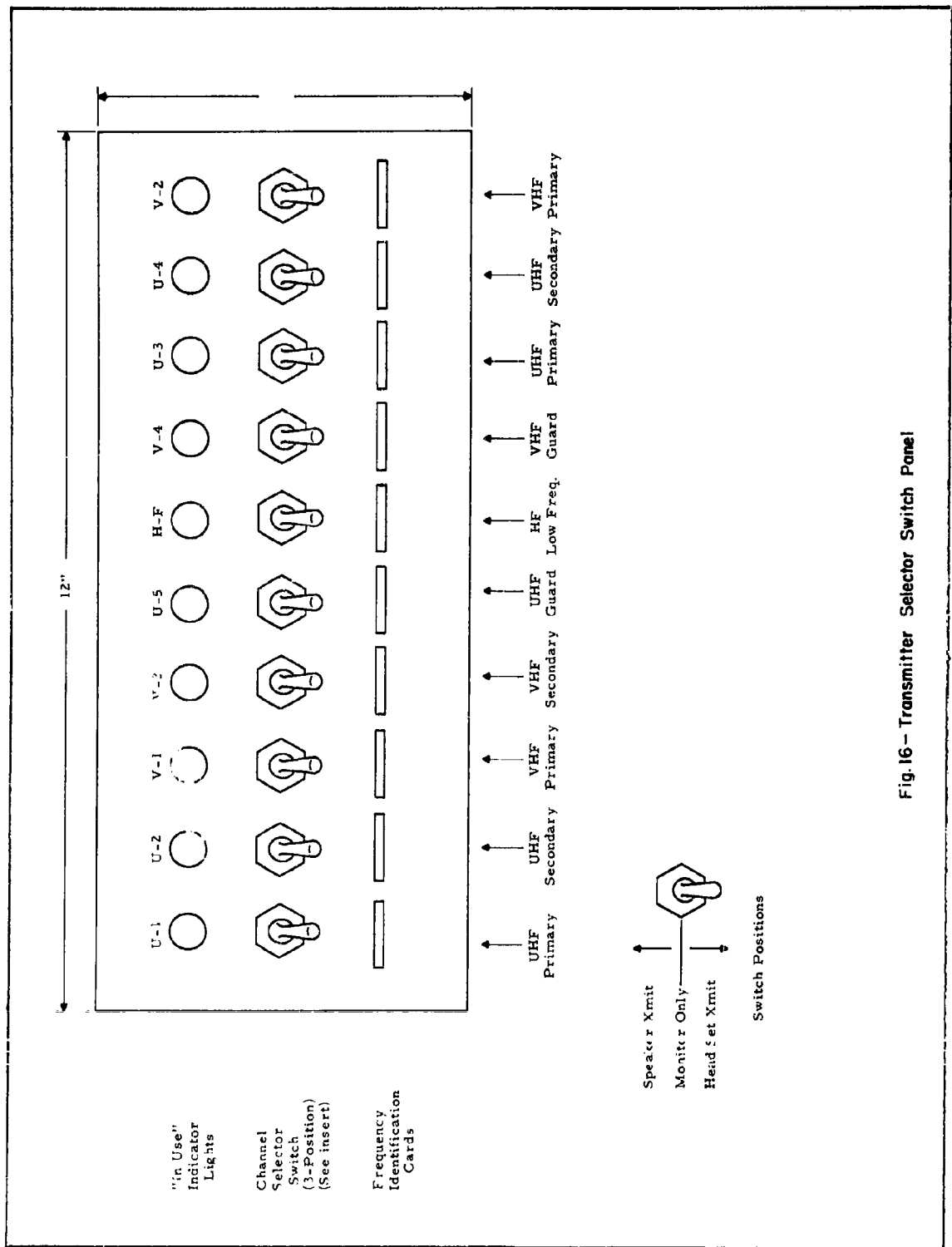


Fig. 16 - Transmitter Selector Switch Panel

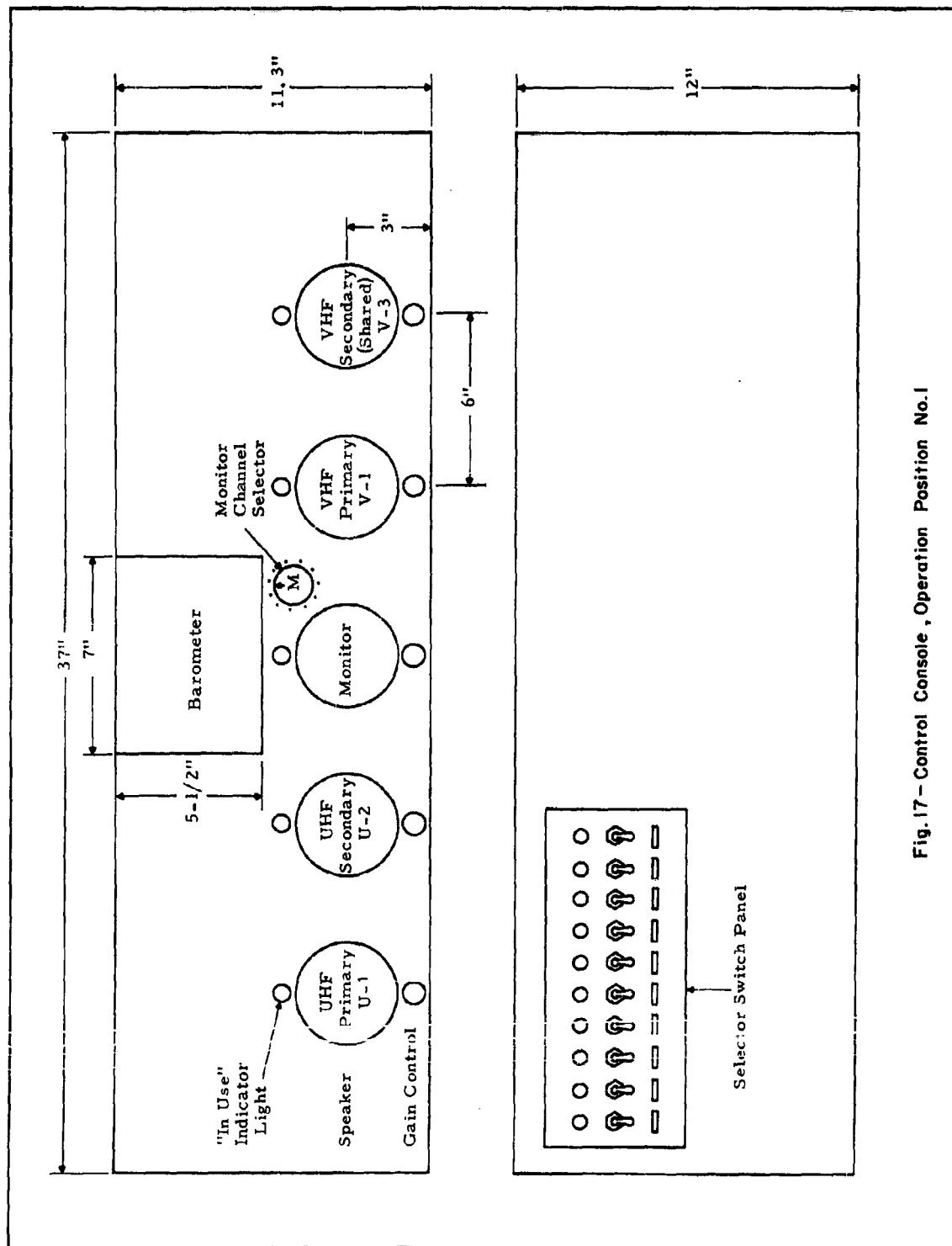


Fig. 17 - Control Console, Operation Position No. 1

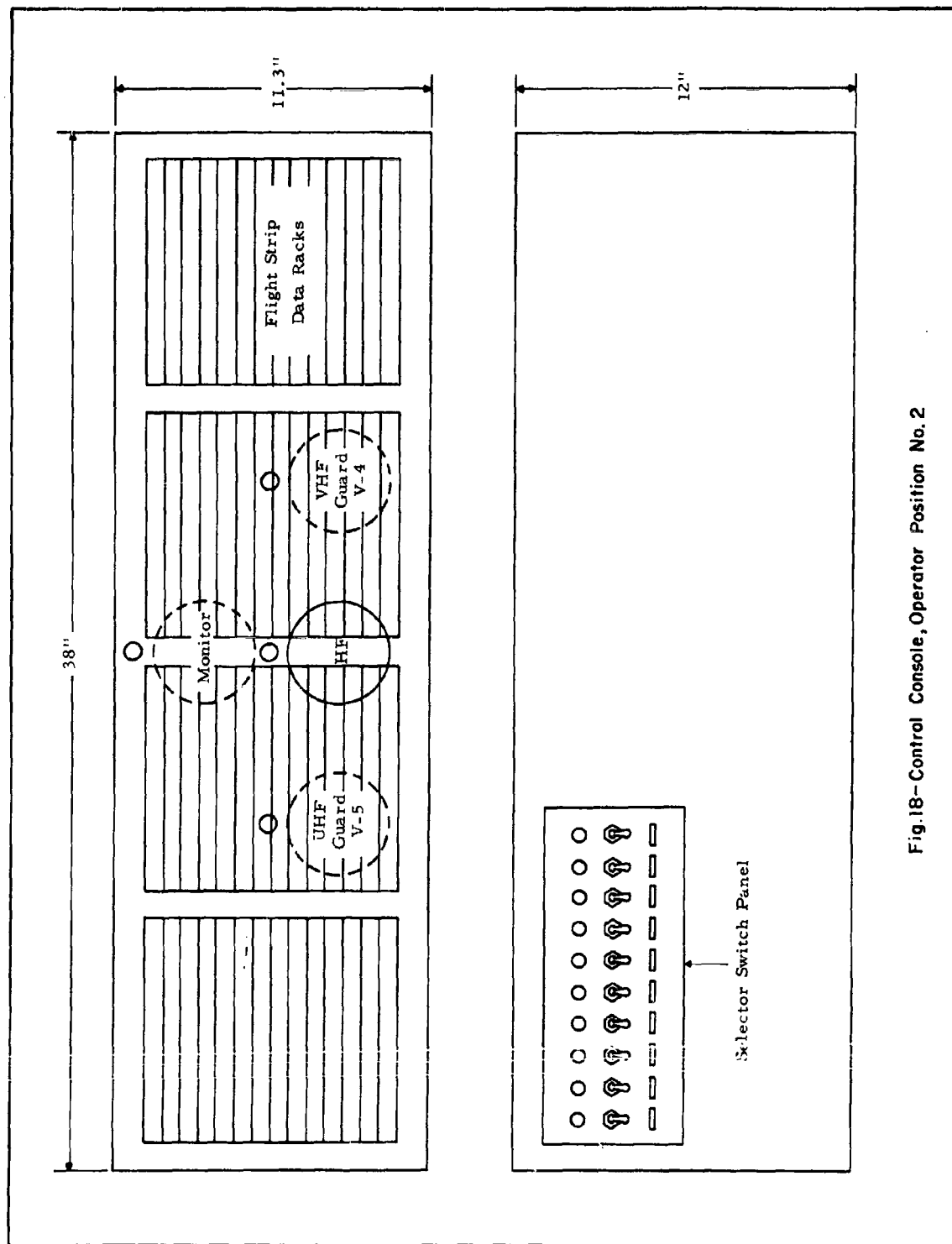


Fig.18-Control Console, Operator Position No. 2

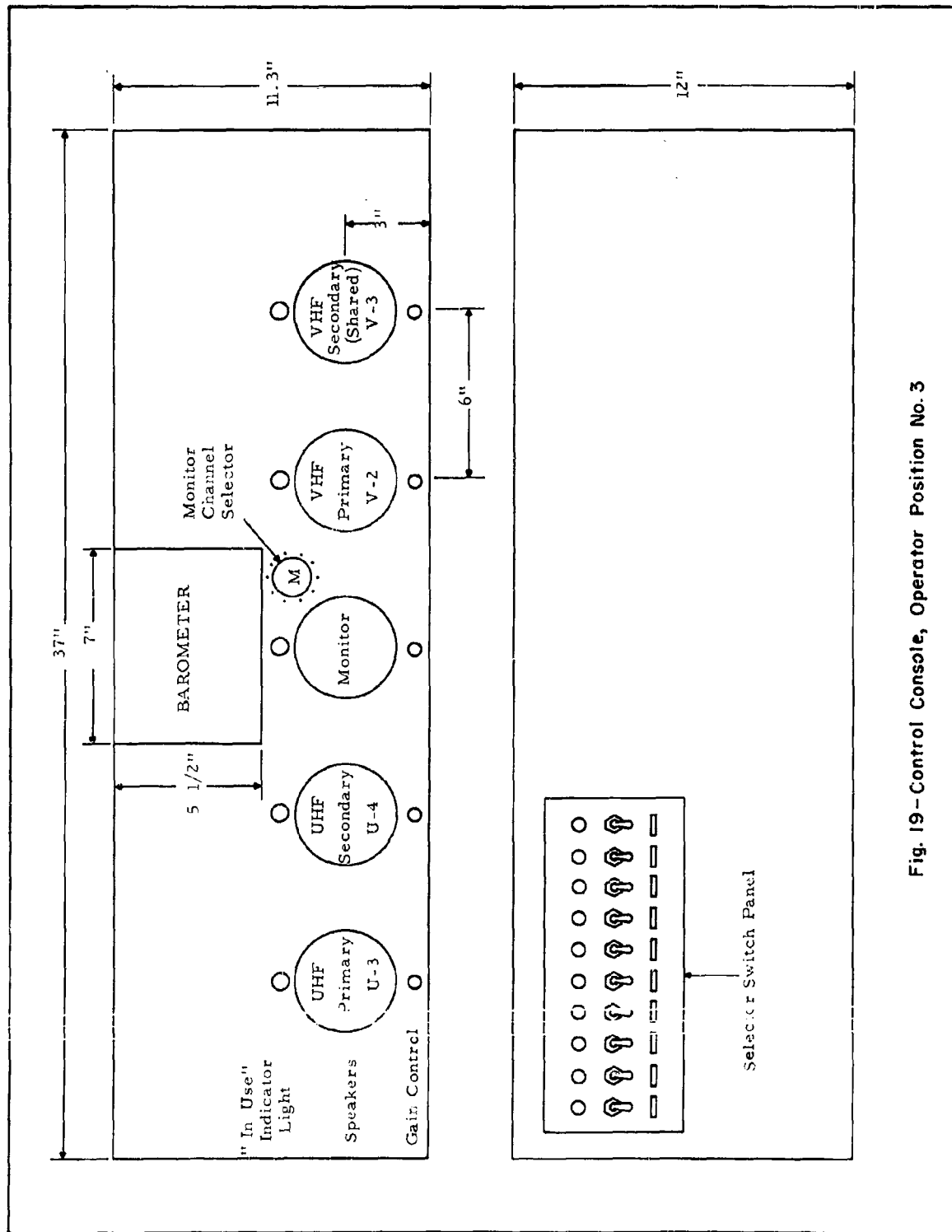


Fig. 19-Control Console, Operator Position No. 3

a. Position One

Normally the operator in position one will act as a local controller, and will control all aircraft in the vicinity of the airfield, under VFR conditions. There are five speakers in the number one (local controller) position, a UHF primary, a UHF secondary or back-up, a monitor, a VHF primary, and a VHF secondary or back-up. The four UHF/VHF speakers correspond to switches U-1, U-2, V-1, and V-3 on the selector switch panel (Figure 16), and are the four circuits normally operated by operator one. All of the four UHF/VHF speakers are connected to separate transceivers, with the exception of the VHF secondary speaker which is one of a pair of speakers connected to a single transceiver and activated by a single switch (V-3). The second speaker of the pair is in operator position three, and these two operators (one and three) share the single VHF secondary or back-up transceiver. This shared arrangement is considered adequate due to the decreasing numbers of aircraft equipped with VHF.

The monitor speaker (one in each of the three operator positions) enables any of the three operators to monitor any conversation of any other operator. It is activated by moving the desired circuit switch to the middle or MONITOR position, and selecting the corresponding channel on the monitor channel selector directly above the monitor speaker.

b. Position Two

The operator at position two is a data man and will normally act as "bookkeeper" for the other two positions. His main duties consist of: (1) accepting flight plan information, (2) posting the flight progress strips located in the racks on the face of his speaker panel, and (3) acting as communications coordinator for the facility. There are four speakers in the number two (data) position, a UHF guard, a monitor, an HF, and a VHF guard. The two UHF/VHF speakers and the one HF speaker correspond to switches U-5, V-4, and HF on the selector switch panel (Figure 16), and are the three circuits normally operated by the operator at position two. The monitor has the same function as in position one. The UHF/VHF guard transceivers act as emergency frequencies, and may be used to provide UHF/VHF DF information. The single HF transceiver serves as a method of direct communication with other units for the relaying of flight data, operational messages, time checks, status reports, and weather.

c. Position Three

The operator at position three will act as a ground controller, and will control all traffic moving on the surface of the airfield. There are five speakers at the number three (ground controller) position, a UHF primary, a UHF secondary or back-up, a monitor, a VHF primary, and a VHF secondary or back-up (the latter sharing a single transceiver and selector switch with position one). The four UHF/VHF speakers at this position correspond to switches U-3, U-4, V-2, and V-3 on the selector switch panel (Figure 16), and these are the four circuits normally operated by the operator at position three.

To increase operator efficiency, the switches on the selector switch panels at each position are color coded as follows:

Red	-- guard frequencies (U-5 and V-4).
Green	-- local controller frequencies (U-1, U-2, and V-1).
Yellow	-- ground controller frequencies (U-3, U-4, and V-2).
White	-- shared VHF secondary or guard frequencies (V-3).
Blue	-- HF control frequency (HF).

Also, to aid in monitoring operations, a modulating speaker indicator light is mounted above each speaker to indicate "IN USE" speakers.

D. SURVEILLANCE RADAR SHELTER

1. Shelter Layout

The specification of an adequate layout for the surveillance radar involves consideration of the personnel functions that are likely to occur during operation and the quantity, size and characteristics of the equipment. The equipment required for this shelter is large in size and volume (relative to the total area available for packaging) and has many peculiarities, but, fortunately, the personnel activities do not require an excessively controlled environment.

The modulator transmitter and the receiver both require access to the outside through the side of the van. The modulator transmitter requires two ducts and blowers, while the receiver has an attached wave guide that is routed through the side of the van (see Figure 20). Both the modulator transmitter and the receiver are packaged together, along with the main power supply and a separate modulator transmitter power supply. (See Figures 21 and 22).

Since this equipment generates a great deal of heat, an isolation wall has been proposed. Access doors and pull-out provisions have been incorporated in the wall design to provide an access for maintenance. The wall also contains adjustable louvers to regulate the flow of conditioned air.

By grouping the receiver, main power supply, modulator transmitter, and modulator transmitter power supply together, the air conditioning loads are simplified, and antenna locations are optimized without compromising design for maintainability. Further, this grouping leaves a relatively uncluttered area for maintenance and operational activities, and permits open access to the microwave equipment, which may require frequent adjustment.

Subsequent discussion of the operator functions will point out that the initial alignment of the radar involves the indicator but not necessarily the electronic counter-countermeasures (ECCM) equipment. However, once the operation has proceeded beyond this initial step, the ECCM equipment and the indicator are employed jointly in anti-jamming activities. The ECCM equipment and the indicator are grouped together to permit ease of operation under these conditions. Since the ECCM equipment is the less frequently used of these equipments, it was located above the radar indicator. This places the indicator in the prime visual and reach areas of normal operators (50th percentile), yet still keeps the ECCM equipment well within the boundaries of efficient workspace.

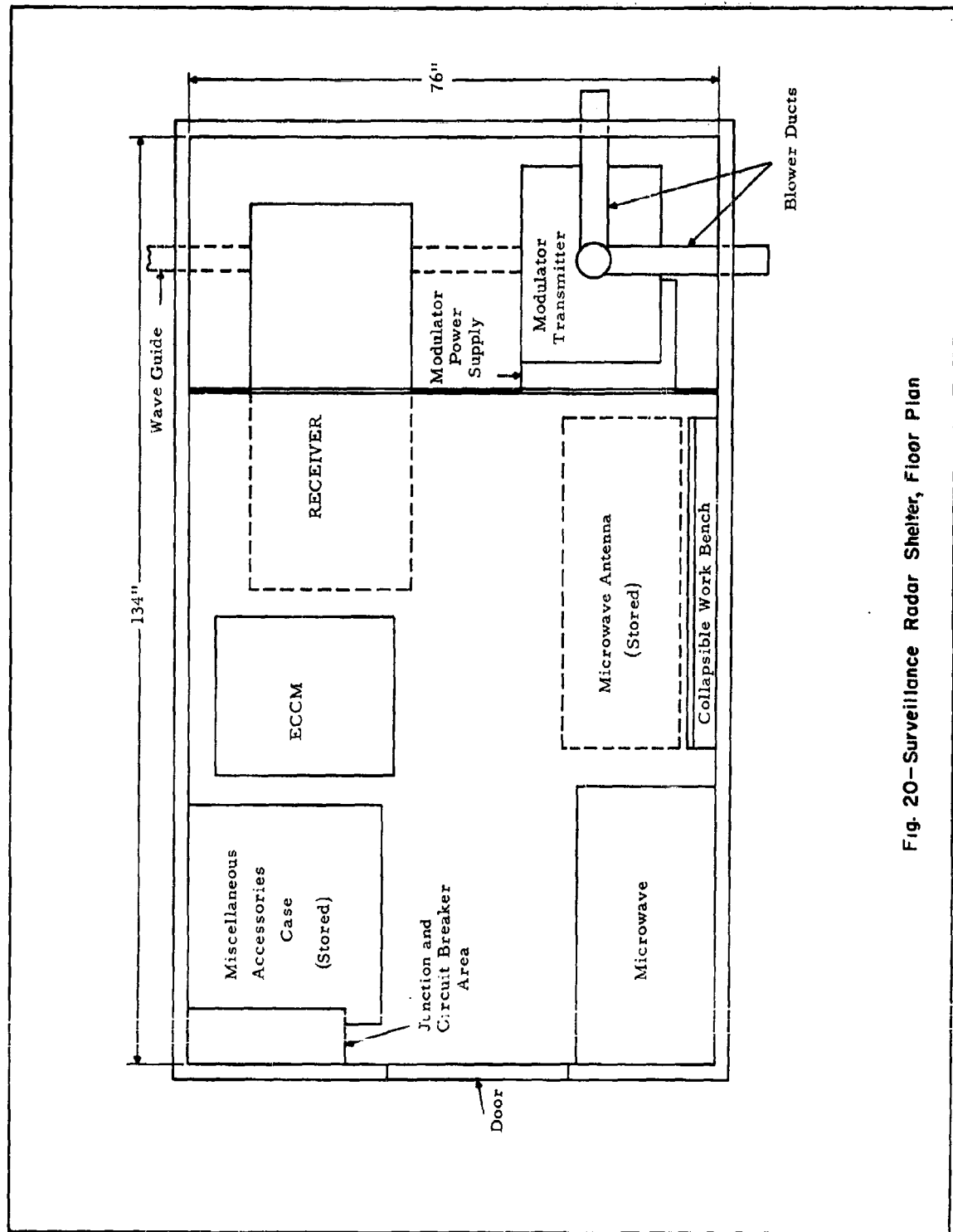


Fig. 20-Surveillance Radar Shelter, Floor Plan

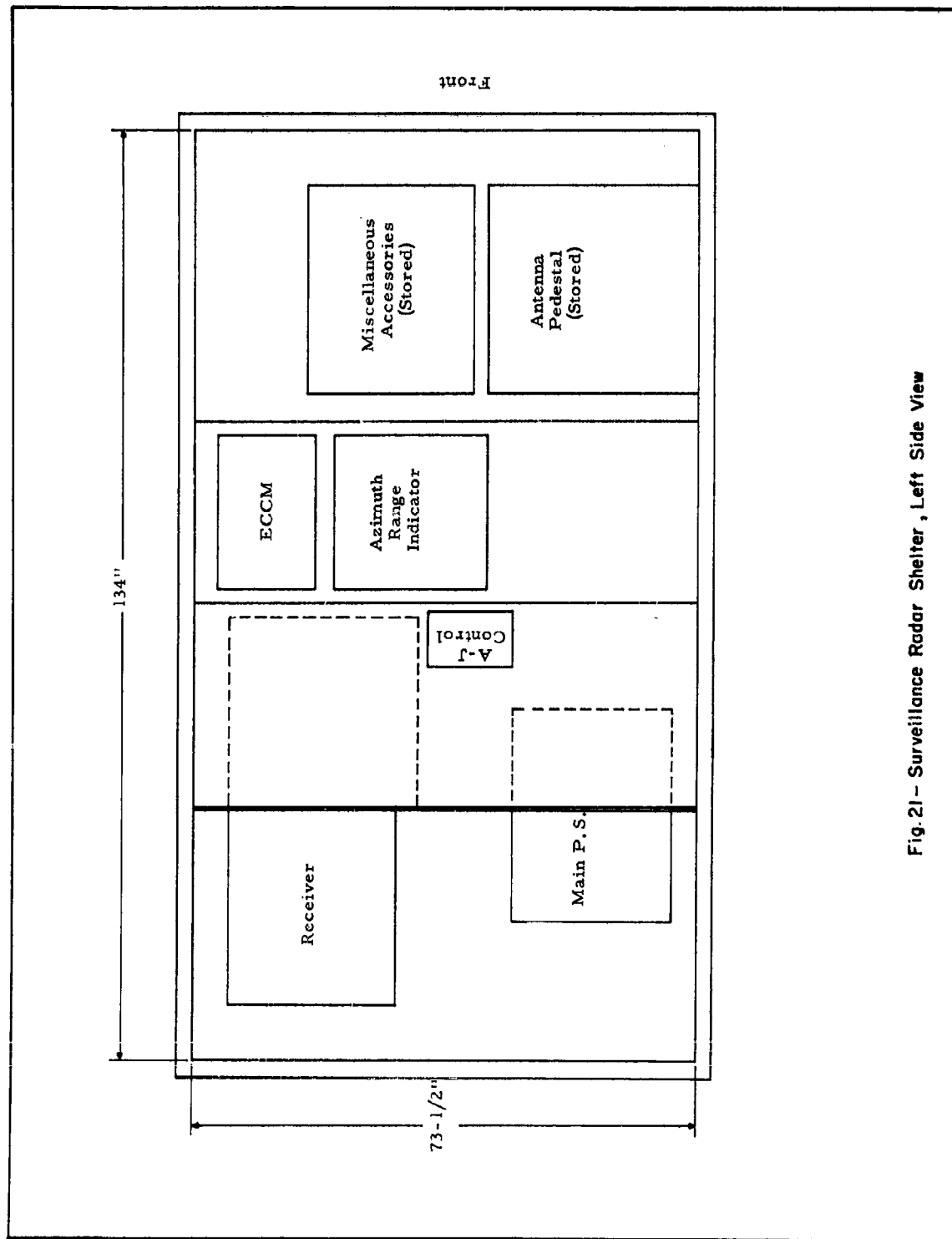


Fig. 21 - Surveillance Radar Shelter, Left Side View

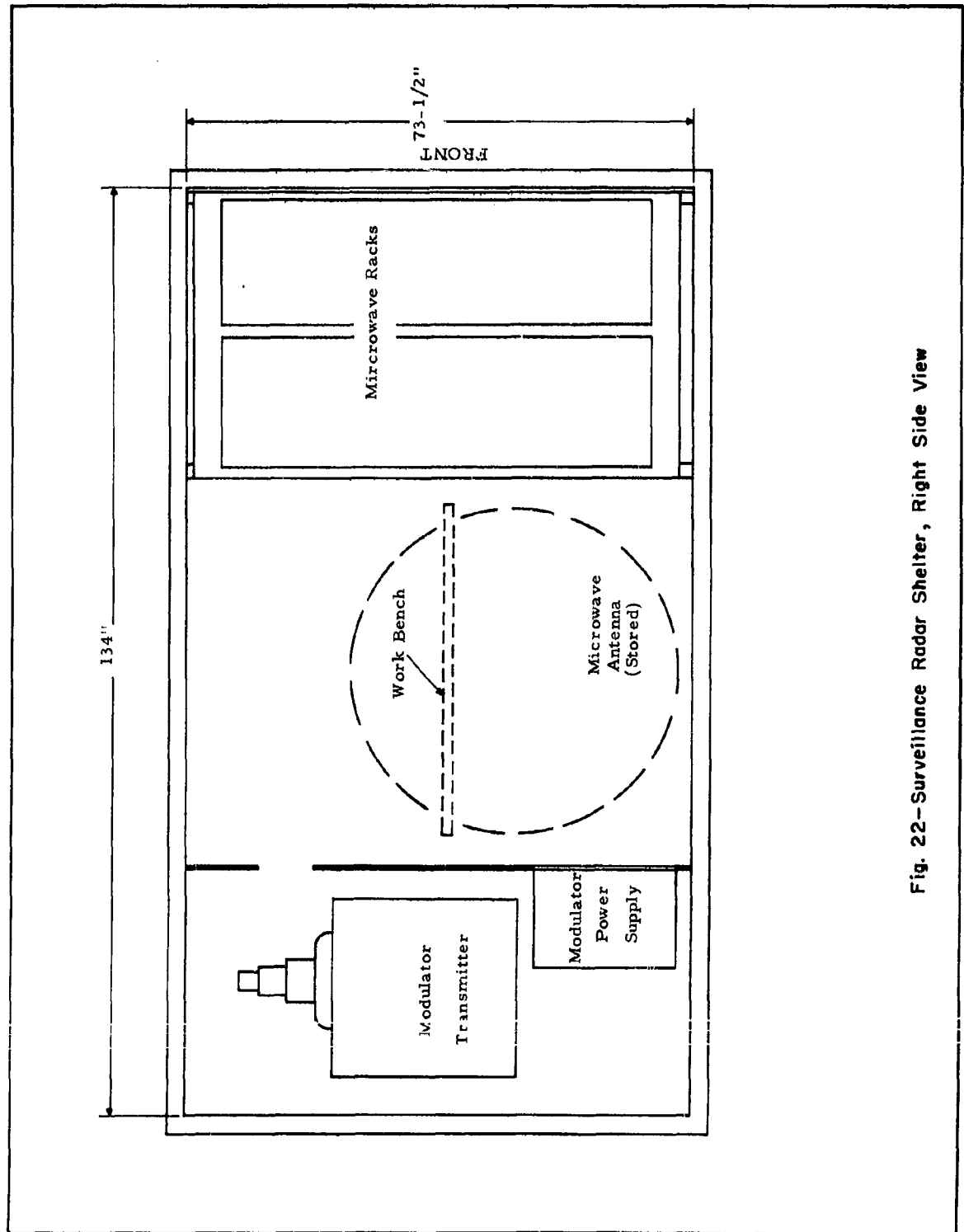


Fig. 22-Surveillance Radar Shelter, Right Side View

Since this shelter must contain facilities for equipment maintenance, a large, well lighted work surface is also provided. The work table in this area collapses to provide space for antenna storage during transit.

2. Communications Capabilities

The communication equipment in the surveillance radar shelter is limited to the inter-communication system. However, this communications link is invaluable for effective system performance since it will be used to coordinate the initial radar and indicator alignment. During system operation, it is used as a link between controllers in the IFR shelter and maintenance personnel in the surveillance radar shelter to coordinate subsequent readjustments.

All ECCM operations will be controlled via the inter-communication system when the need for such measures arises. The probable steps involved in both radar and ECCM operations will be discussed in the following subsection.

3. Number and Function of Operators

Only one operator will be required for normal operation of the surveillance radar facility. However, during set-up some extra help will be required for positioning the antennas because of their weight and installation location.

The radar technician in the surveillance shelter will begin operation by aligning and adjusting the radar. During this phase, constant contact will be maintained with the controllers who operate the surveillance indicators in the IFR facility. Minor "convenience" adjustments (e.g., brightness) may be made at the slaved indicators in the IFR shelter, but major adjustments will not be remoted and will have to be made by the technician in the surveillance shelter.

The goal of these adjustments will be to remove as much information distortion as possible. The major source of distortion will most probably arise from the microwave link, but additional distortion can also be caused by a poorly adjusted slave indicator, or from poor adjustment of the primary radar indicator.

The ECCM equipment will contain approximately twelve pre-set fixes. Each will be controlled by a switch, and operation will be relatively simple. The complications arise in the decision-making process which determines which fix or combination of fixes should be employed for anti-jamming.

This process consists of the following steps: (1) determination that jamming is occurring, (2) assessment of the characteristics of the jamming signal, (3) decision as to which fix or fixes to employ as anti-jamming measures, and (4) evaluation of the effectiveness of the anti-jamming fixes that were employed and implementation of any changes in ECCM strategy to increase anti-jam effectiveness.

The first step is a "go- no go" decision that the radar either is or is not being jammed. It is possible that the controllers may be the first to perceive the effects of jamming, in which case they would notify the technician in the surveillance shelter and await his action. However, there is a much higher probability that the technician will become aware of the presence of jamming signals at least as soon as the operator and attempt to correct the situation. In either case, the controller in the IFR van can actively participate only in this first step in the decision-making process. From this point on, only the technician in the radar shelter has the equipment necessary to employ ECCM.

Once it has been decided that the radar is being influenced by jamming signals, the technician, with the aid of an A-scope, must assess the characteristics of the jamming signal. Then he can decide which fix(es) he should employ to counter the jamming signal. The next step then is to evaluate the ECCM strategy employed by determining whether or not the effects of the jamming signal are overcome, and to continue the ECCM operation until an adequate counter-countermeasure is obtained.

E. PAR (PRECISION APPROACH RADAR) SHELTER

1. Shelter Layout

In achieving an adequate layout for the PAR shelter, primary consideration was given to the personnel functions likely to occur during operation, and secondary consideration to provision of adequate storage area for the necessary antennas during transit. The present layout of equipment offers the best solution to these operational and storage problems.

Figures 23, 24, and 25 show the general configuration along with equipment layout and the single operator position. The suspension of the radar transmitter/receiver from the ceiling facilitates antenna storage. The radar transmitter/receiver was positioned in the far left corner to allow maximum accessibility for alignment and maintenance, and was designed to rotate 360 degrees.

As in the surveillance shelter, maintenance is one of the primary functions to occur, and a large, well lighted work surface is provided for this purpose. The total work surface area was designed to accommodate the largest piece of equipment housed in the shelter. The work table folds flat against the wall to facilitate antenna storage, and is 35 inches high when in working position, (the optimum height for a standing bench operation). The work table was placed in the middle of the shelter along the right wall to allow maximum operator work area, and to provide adequate pull-out space for the UHF/VHF transceiving equipment stored beneath the table.

The PAR indicator was located in the front left corner near the door to allow efficient access for operation, without interfering with the maintenance functions of the shelter.

2. Communications Capabilities

Communication capabilities in the PAR shelter include UHF/VHF air-ground-air communications, and the inter-communication system. The UHF/VHF air-ground-air communications will serve for emergency final approach control in the event that the IFR facility should become inoperative. The inter-communication system will provide both a link with the VFR tower shelter (for coordination of emergency clearances), and a link with the IFR shelter (for initial coordination

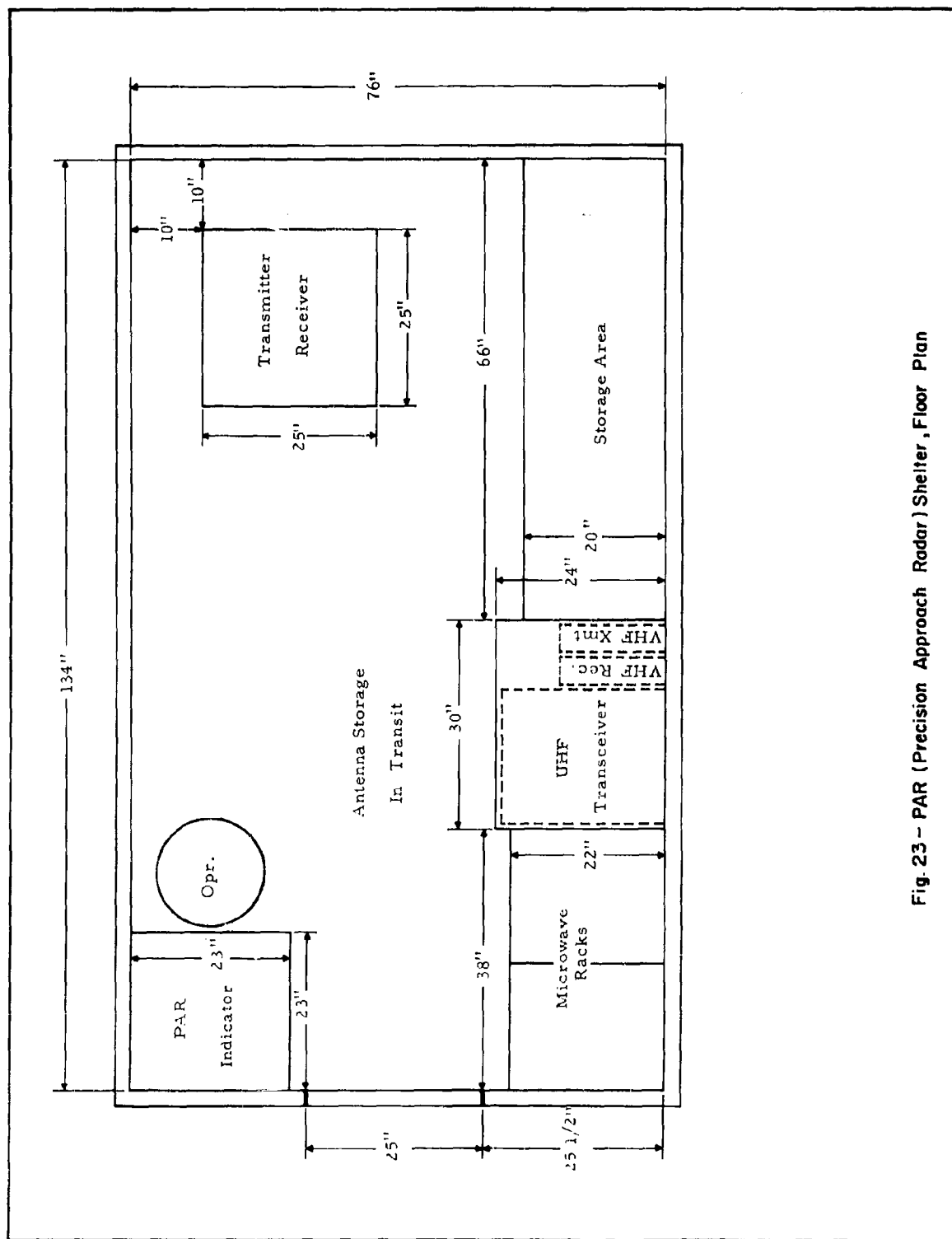


Fig. 23 - PAR (Precision Approach Radar) Shelter, Floor Plan

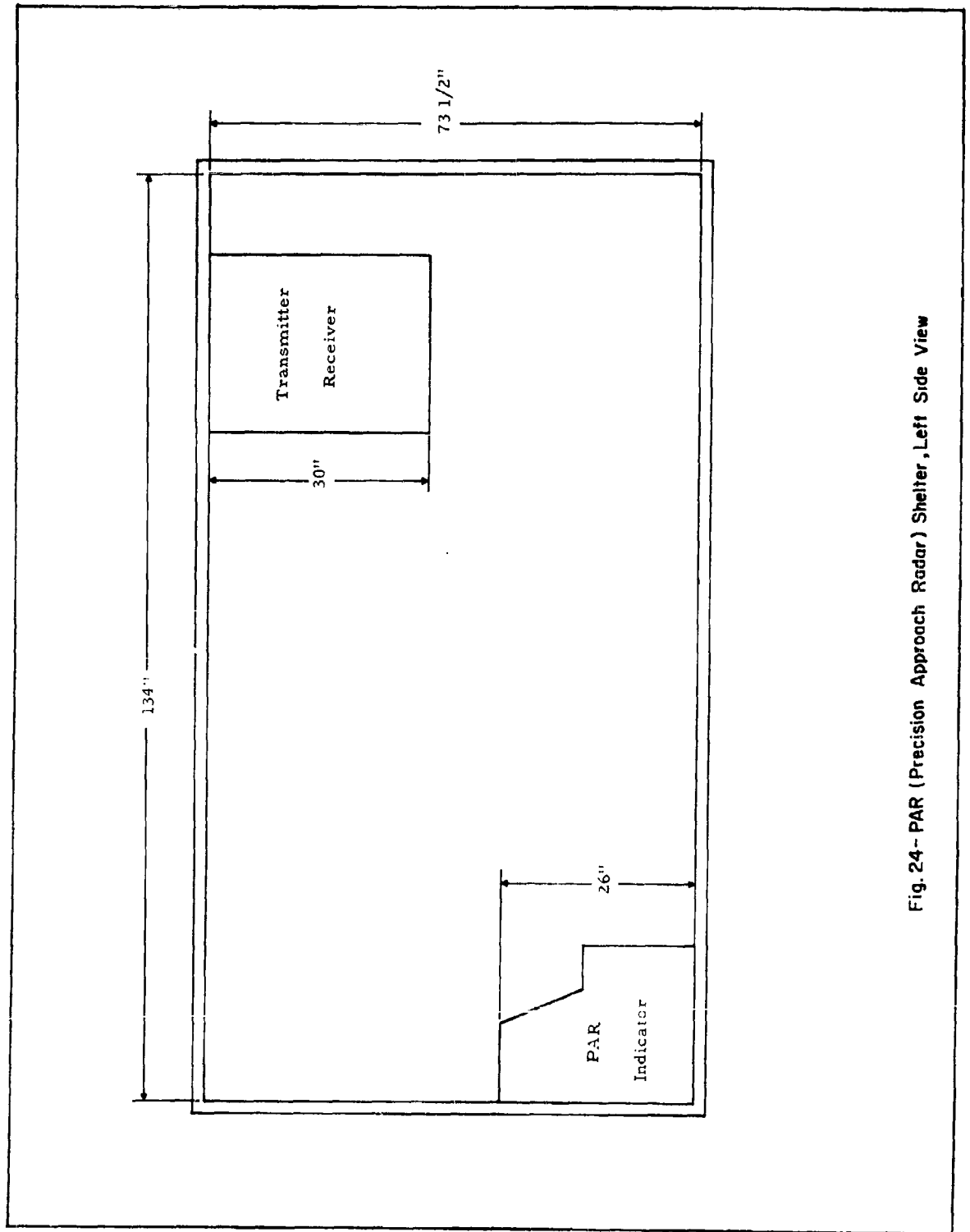


Fig. 24- PAR (Precision Approach Radar) Shelter, Left Side View

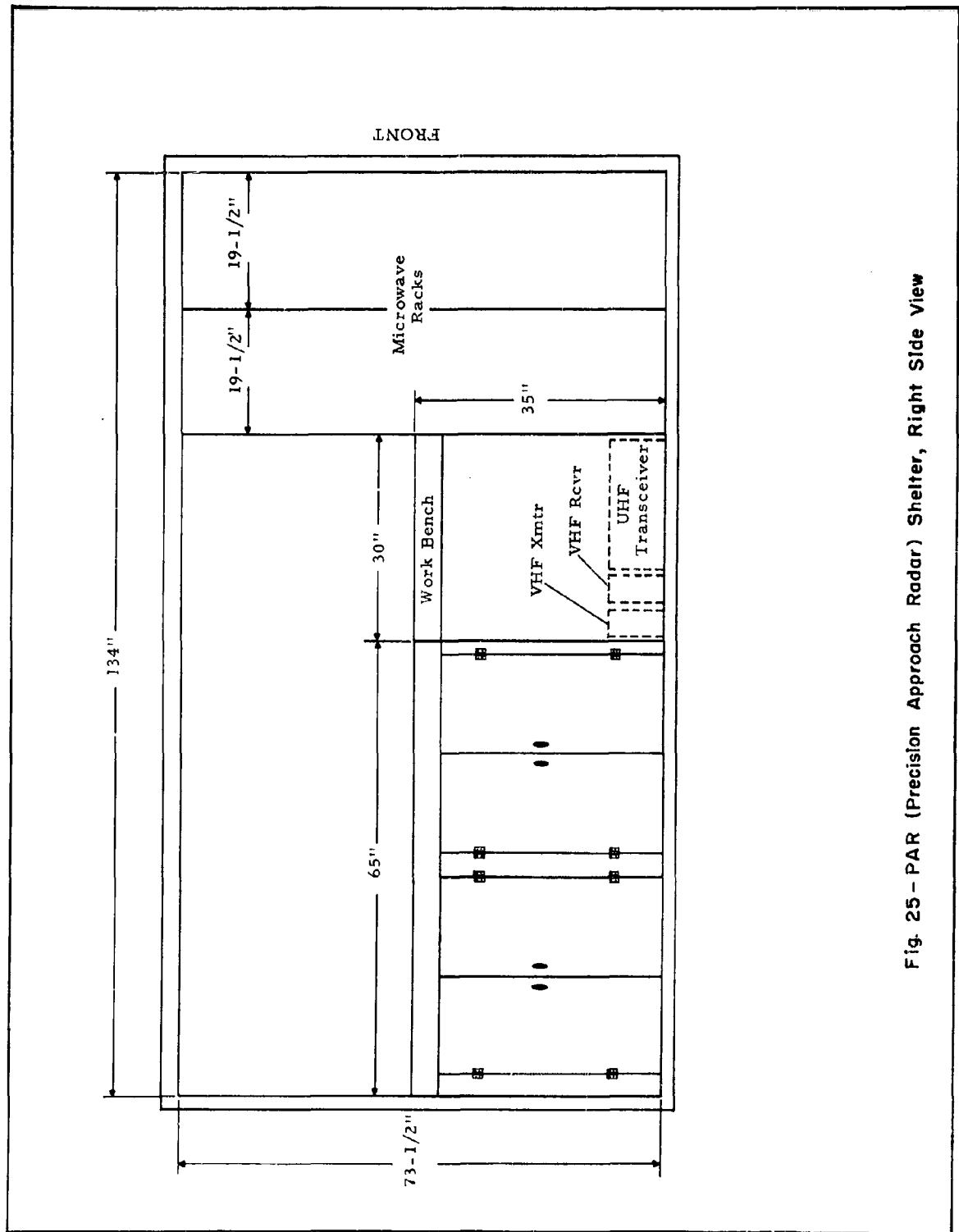


Fig. 25 - PAR (Precision Approach Radar) Shelter, Right Side View

of radar and indicator alignment, coordination of major and minor adjustments, and maintenance).

3. Number and Function of Operators

Normal set-up and operation of the PAR facility requires only one operator, with the exception of antenna installation which may require temporary extra help.

The radar technician in the PAR shelter will begin set-up procedures for operation by siting the equipment in relation to the runway or runways which are being used for radar landings. The next step involves assembling the equipment and installation of antennas and drive assemblies. Once the site is selected and the antennas installed, the runway centerline, touchdown point, and runway parallel are marked with the siting target reflectors. After placement of the target reflectors, the radar set is oriented and aligned to each different runway by means of a telescopic sight.

Following alignment of the transmitter/receiver group, the technician commences with the turn-on procedure, tune-up, and cursor alignment. The courseline cursor is aligned using the return signals from the runway center reflectors, the glidepath cursor aligned using the touchdown reflectors, and the approach angle of the azimuth courseline cursor aligned with the runway parallel reflector. This cursor alignment procedure is carried out for all runways to be used. After cursor alignment is completed the CRT display is adjusted for intensity, focus, video gain, centering, IF gain, AZ and EL control, LO tune, AZ tilt, EL target, mode, range, altitude, pulsewidth, glidepath angle, etc.

During the turn-on and tune-up phases, constant contact will be maintained with the controllers who use the PAR indicators in the IFR facility. As in the case of the surveillance radar, minor adjustments may be made at slaved indicators in the IFR shelter, but the major adjustments must be made by the technician in the PAR shelter. The PAR to IFR microwave link is subject to the same sources of distortion as the Surveillance to IFR link, and will require similar procedures to minimize distortion of information.

Under emergency conditions (e.g., if the microwave equipment of the IFR facility were inoperative,) the equipments in the PAR shelter must be capable of directing precision approach landings. Under these conditions the

controller would operate from the PAR facility, and the landing rate would be greatly reduced since the necessary transfer of control from the feeder position to the PAR controller would have to occur over the intercommunications system.

II. AMBIENT CONSIDERATIONS

A. INTRODUCTION

Unfavorable environmental conditions can cause severe degradations in human performance of the type required in the Augmented "4 Wheels" System. In addition to interfering with the visual and auditory transmission of information, an unfavorable or inadequate environment can cause discomfort, nausea and fatigue, and can result in severe decrements in vigilance, discrimination, and reasoning tasks.

The environmental conditions of prime importance to this system include noise, illumination, air temperature, humidity and air velocity. Each of these is discussed in terms of maximum levels or ranges of tolerance. The following table summarizes recommendations made in the areas of noise, heat, humidity, and air velocity.

<u>Condition</u>	<u>Outside</u>	<u>Inside</u>
Noise	100 db max.	80 db max.
Heat	----	70-80° F.
Relative Humidity	----	40-60%
Air Velocity	----	100 ft/min.

The following sections enumerate in more detail the various problem encountered within the above mentioned environmental areas, and discusses applicable solutions to these problems in regard to the Augmented "4 Wheels" System.

B. NOISE

Noise control has been a problem throughout Augmented "4 Wheels", and it is exceedingly important in facilities such as the Communications, VFR Tower, and IFR shelters where extensive voice communications occur. The noise level is affected by such things as human voice communications, air conditioner and power generator noise, maintenance and operative equipment noises, air velocity noises (within shelters), and noises associated with aircraft operations. For efficient human operation, this noise level should be kept to a maximum of 80 db inside shelters and 100 db outside the shelters. When noise levels exceed these values, vocal communications become increasingly difficult, resulting in information loss and/or time delays, undue operator strain and possible fatigue. These factors are especially critical under IFR conditions, where information losses, fatigue, and the need to repeat communications could result in loss of human life and valuable equipment. Unfortunately the noise problem is compounded in both the IFR and Communications shelters. Not only do extensive vocal communications occur within these shelters, but the substantial heat producing equipment and the number of operating personnel creates a heat dissipation problem, and necessitates the use of two air conditioners.

Noise reduction methods, which at this time seem to be the best solution to these particular noise problems, include acoustical treatment of shelter walls and ceilings, vibration mounting of equipment, provision of acoustical barriers between work areas and noise sources, remote packaging of noise producing equipments such as air conditioners and power generators, and provision of a multiple venting system to help absorb air conditioning and velocity noises within shelters. This last method includes sound baffles in the air conditioning ducts, and introducing the conditioned air into a false ceiling to reduce the air velocity.

C. ILLUMINATION

The required ranges of illumination will vary somewhat from shelter to shelter, and even within a given shelter depending on the specific operator functions. The communications shelter will have little problem in this regard since uniform, high intensity lighting (25-30 ft. candles) will be adequate for all tasks. The ASR and PAR shelters should have adjustable illumination over

a wide range (2-30 ft. candles) to permit a corresponding range of functions, from actual use of the CRT in controlling aircraft, to checkout and maintenance.

The major illumination problems will occur in the VFR tower and IFR shelters. The tower will, of course, require a transparent glass enclosure to provide complete external visibility. The main illumination problems encountered in such a configuration will be the use of lighting which is flexible enough to permit sufficient visibility, without glare, under daylight conditions and still prevent loss of dark adaptation during night operations. This will require the use of edge-lighting and/or red light filters and the capacity for light shields to screen off the data position which will require greater levels of illumination.

The IFR (RAPCON) shelter will present further illumination problems. The light levels in this area must be low enough to permit operation of the CRT indicators and yet still permit the controllers to record and read data and operate communications equipment. The exact levels of illumination to be specified will be dependent upon the light outputs of the CRT displays selected, but it certainly will be necessary to screen off this area from the tower to prevent daylight from interfering with CRT operation. It may also be necessary to use some method of polarization filtering to prevent ambient illumination from deteriorating controller performance.

Lighting for maintenance operations must be considered throughout the system. The human engineering effort has outlined the requirements for convenience receptacles where maintenance may be required, and the provision of maintenance and troubleshooting lights in applicable consoles.

Other lighting considerations include exterior shelter lights for identification at night, and lighting for grounds area between shelters for personnel safety.

D. AIR TEMPERATURE, HUMIDITY, AND VELOCITY

In order to prevent undue fatigue and human performance decrements, temperature and humidity must be carefully controlled. The temperature inside the shelters should range between 70 and 80 degrees F. and the relative humidity between 40 and 60 percent. Due to the compactness of the Augmented "4 Wheels" subsystems (shelters), heat dissipation is a particular problem. The presence of heat producing equipments operating in close proximity with human operators in such relatively small areas will necessitate a great amount

of air conditioning. This creates a problem since the maximum desirable air velocity is only 100 ft/min., and values in excess of this figure produce distinct drafts and air "blasts". The problem is further complicated in those shelters requiring two air conditioners because of heat dissipation requirements. Two air conditioners operating through a single duct would produce an air velocity of about 830 ft/min. -- considerably above the desired maximum of 100 ft/min.

At this time, the best solution to the problem of excessive air velocities appears to be the use of multiple venting system. The most practical means of achieving a multi venting system within the Augmented "4 Wheels" shelters seems to be through the use of perforated false ceilings. This would essentially consist of a plenum chamber formed by the false ceiling, into which the conditioned air would be ducted. The air stream would be forced through the perforations, producing a multi venting effect and permitting even cooling over the entire interior of the shelter. The false ceiling will also act to reduce noises associated with high air velocities and exterior noises transmitted through the ducting system.

III. COMMON DESIGN CRITERIA

A. INTRODUCTION

Although the equipment for Augmented "4 Wheels" is to be "off the shelf" wherever possible, many modifications will no doubt be required in order to achieve an integrated system. At the present time, there is not yet enough information available to specify the exact nature of these modifications. The purpose of the following section is to anticipate the kinds of modifications that may be required, and to specify human engineering guidelines for use during the modification of "off the shelf" equipment.

B. GENERAL CONSIDERATIONS

1. Standardization

- a. Insofar as possible, selection of components, marking, coding labeling and arrangement schemes (equipment layout) should be standard for all system equipment. Where equipment units are manufactured by different contractors, uniformity should be accomplished by agreement with the procuring authority.

2. Fail-Safe Design

- a. All reasonable effort should be directed toward the achievement of a fail-safe design in those areas where high reliability cannot be expected and the consequences of failure will be severe, such as destruction of equipment or injury to personnel.

3. Designation of Functional Areas

- a. Whenever it is desired to set apart, for purposes of ready identification, distinct, noncritical functional areas (those not associated with emergency operation), these areas should be outlined by black lines approximately 1/16 inch wide.
- b. Functional areas of emergency or extremely critical operations should be set apart by a 3/16 inch red border. Red should be in conformance with Color No. 31136, Federal Standard 595.

4. Fail-Safe Operation

- a. Whenever feasible, displays should be so designed that the failure of the display and/or display circuitry should be immediately and readily apparent to the operator.

- b. Failure of display circuitry should not cause a failure in the equipment associated with the display.

C. LABELING

1. Controls and Displays

- a. Each control and display should be identified as to function.
- b. Labels should appear either on or immediately adjacent to (preferably above) the controls and displays to be identified and should be so located as to preclude association of a label with the wrong control or display.
- c. The location of labels in relation to controls and displays should be consistent on all system equipment.
- d. Labels should be brief. Although the nomenclature should clearly indicate the function being displayed or controlled, highly similar names should be avoided. Abbreviations, where required, should be common or meaningful and should conform with MIL-Std-12A and ANA Bulletin 261.
- e. Lettering on the panels should be black, Color No. 37038, Fed. Std. 595.
- f. Capital letters should be used in preference to lower case.
- g. Abstract symbols (squares, Greek Alphabet, etc.) should not be used as labels. Common meaningful symbols such as the per cent sign, plus sign, etc., are acceptable.

2. Units

- a. Wherever possible, the outside covering of manufactured parts such as resistors, condensers, and tubes, should be stamped or coded with relevant information concerning electrical characteristics of the part.
- b. Where space permits, terminals should be labeled with the same code symbol as the wire attached to it.
- c. Labels should be etched or embossed into the component or chassis rather than merely printed or stamped on the surface. If surface labels must be used, decals, silk-screened or stamped labels are preferable to stenciled labels.
- d. Labels should not be hidden by units and parts. For example, labels on the chassis should not be placed under the parts which they identify.
- e. Bill of material or maintenance nomenclature should not be placed on the front of the panel, but rather behind the control panel where possible in order to facilitate trouble-shooting and maintenance.

D. DISPLAYS

1. Cathode-Ray Tubes

- a. Since interpretation of scopes requires a high degree of skill, and necessary skills may be limited, the use of scopes should be minimized.
- b. The display should resolve as much detail as is required for adequate interpretation of the displayed information.
- c. The brightness contrast relationship between the signal and background should be sufficiently high to afford good visibility.

- d. A 16-inch viewing distance should be used whenever practical. Where periods of scope observation are short and where it is important that dim signals be detected, the recommended 16-inch viewing distance can be reduced to 10 to 12 inches.
- e. Whenever possible, the scope face should be in a plane which is perpendicular to the operator's normal line of sight.
- f. The ambient illumination in the CRT area should be sufficiently high for other visual functions (setting controls, reading instruments, maintenance, etc.) but should not interfere with the visibility of the signals on the CRT.
- g. Ambient room illumination should not contribute more than 25% of the screen brightness through diffuse reflection and phosphor excitation.
- h. Room illumination may be sufficiently high for other visual tasks if the scopes are adequately hooded or shielded from the light.
- i. Surfaces immediately adjacent to the scope should be in a brightness range from equal to the brightness of the screen to 10% of this brightness. No light sources brighter than the radar signals should be in the immediate surround.
- j. Surfaces immediately adjacent to the scope should have a dull matte finish. The reflectances of the surfaces should be such that the resultant brightnesses are consistent with the recommendations above.
- k. The design of scales and other devices used to get quantitative data from the display should be such as to maximize accuracy and speed.

E. CONTROLS

1. Use of Controls

- a. Controls should be distributed so that no one limb is overburdened.
- b. Control movements should be in the directions that conform with population stereotypes.
- c. For high precision over a wide range of adjustments, multi-rotation controls should be used.
- d. Adjustments should be divided into discrete steps when possible, using detent controls.
- e. With the exception of standard valve controls, rotary controls should always turn to the right (clockwise) to increase, left (counterclockwise) to decrease. Controls should be so labeled by means of arrows and appropriate legends.
- f. Valve controls should be provided with a double-ended arrow with "open" or "close" at or beside the tip of each arrow.

2. Prevention of Accidental Activation

- a. Controls requiring protection should be located and oriented so that the operator is not likely to hit or move them accidentally in the normal sequence of control movements. Controls requiring protection are particularly those whose inadvertent operation can result in equipment or personnel hazards or in delays, and possibly those which are "hidden" and whose inadvertent operation would cause locating difficulty and time consuming adjustment difficulties.
- b. Any method of protecting a control should not also preclude its being operated quickly when desired.

- c. Recesses, shields, or physical barriers placed around the control can be used as protective methods.
- d. Covers or guards should not be used if the control is used frequently unless the guard can be locked out of position.
- e. Interlocks can be provided so that extra movement (e.g., a side movement out of a detent position, a pull-to-engage clutch, etc.) or the prior operation of a related or a locking control is required.
- f. Resistance, friction and spring loading, viscous damping, or inertia can be built into the control so that definite and/or sustained effort is required to actuate it.

F. MAINTAINABILITY

1. Unitization of Equipment and Functions

- a. Unless structurally or functionally not feasible, all equipment should be designed in such a manner that rapid and easy removal and replacement of malfunctioning units can be accomplished by one operator.
- b. Unitization of system equipment should be carried at least to the level of the diagnostic capability of the test equipment and/or operator. That is, if the capability exists to isolate a malfunction, then that component or part of the assembly should be packaged so as to be quickly and easily removed and replaced.
- c. Where possible, units serving the same function in different applications should be designed to be interchangeable.
- d. The number of inputs to and outputs from each unit should be kept to a minimum by grouping of functions so that a minimum of criss-crossing of signals between units is required.

- e. Where consistent with maintenance concepts, functions should be so unitized that it is possible to check and adjust each unit separately.

2. Location of Components

- a. Parts should be mounted in an orderly array on a "two dimensional" surface and not "stacked" one on another, i. e., the lower layer not supporting the upper layer of units.
- b. Large manufactured parts which are difficult to remove should be so mounted that they do not prevent convenient access to other parts.
- c. Components should be placed so that:
 - (1) There is sufficient space to use test equipment and other required tools without difficulty or hazard.
 - (2) Structural members of the units and chassis do not prevent access to components.
 - (3) All throwaway assemblies or parts are accessible without removal of other components.
 - (4) Delicate components should be located or guarded so that they will not be damaged while the unit is being handled or worked on.
 - (5) If screwdriver adjustments must be made blind, mechanical guides should be provided, or the screws mounted so that the screwdriver will not fall out of line.
- d. Sensitive adjustments should be located or guarded so that they will not be disturbed.
- e. Internal controls should not be located close to dangerous voltages.

- f. Components of the same or similar form, but of different functional properties, should be mounted with a standard orientation throughout the unit, but shall be readily identifiable, and not physically interchangeable.

3. Size and Weight of Units

- a. When possible, units should be small and light enough for one man to handle and carry, i. e., weight of removable units should be held below 45 pounds. Units in excess of 45 pounds should have provision for two men lift where the lifting height is not in excess of 5 feet and where the total weight is not in excess of 90 pounds. Units weighing over 90 pounds should have provision for mechanical or power lift.
- b. All units weighing 45 pounds or more should be prominently labeled with their weight.

4. Attachment of Components

- a. Only interconnecting wiring and structural members should be permanently attached to the unit chassis. All parts should be mounted on or as subassemblies.
- b. All units designed to be removed and replaced should be provided with handles or other suitable provision made for grasping, handling, and carrying.
- c. Whenever possible, handles or grasp areas should be located over the center of gravity of the unit so that when the unit is lifted it does not swing or tilt.
- d. Handles which must be grasped firmly should be at least 4-1/2 inches in length and 2 inches in depth, assuming a bare hand.

- e. Handles and grasp areas should be located so that at least 2 inches of clearance from obstructions is provided during handling.

5. Rests and Stands

- a. Rests and stands on which units can be placed should be provided. Where feasible, rests or stands should incorporate provisions for test equipment tools and manuals. Where design requirements permit, the rests and stands should be a part of the basic chassis.
- b. Irregular, fragile, or awkward extensions, such as cables, wave guides, hoses, etc., should be easily removable before the unit is handled.

6. Covers and Cases

- a. The proper orientation of a unit within its case should be made obvious, either through design of the case or by means of appropriate labels.
- b. Where possible, cases should be designed to lift off units rather than units lifted out of cases.
- c. Cases should be made enough larger than the units they cover that wires and other components are not likely to be damaged when the cases are put on or taken off.
- d. Where feasible, guides, tracks, and stops will be provided to facilitate handling and to prevent damage to units and components.
- e. Where space permits, hinged covers should be used to reduce the number of fasteners required.
- f. The method of opening a cover should be obvious. If it is not obvious from the construction of the cover itself, an instruction plate should be permanently attached to the outside of the cover.

- g. It should be obvious when a cover is in place but not secured.
- h. Sharp edges and corners on cases and covers should be avoided.

7. Lubrication

- a. Units containing mechanical components should have provision for lubrication without disassembly, or shall not require lubrication.
- b. When lubrication is required, the type lubricant to be used and the frequency of lubrication should be specified by a label at or near the lube port.

8. Mounting of Units

- a. A minimum number of screws or bolts should be used for unit installation.
- b. Whenever possible, identical screw and bolt heads should be used. This is to enable various panels and components to be removed with one type of tool.
- c. Field removable assemblies and units should be replaceable with nothing more than common hand tools.
- d. Units which are frequently pulled out of their installed position for checking should be mounted on roll-out racks, slides, or hinges
- e. Guide pins or their equivalent should be provided on units for alignment during mounting.
- f. Limit stops should be provided on roll-out racks and drawers. Over-ride of these limit stops should be conveniently accomplished.

- g. Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit should have large enough holes for passage of the screw without perfect alignment.
- h. All interchangeable units should be coded (keyed) so that it is physically impossible to insert a wrong unit. Units should also be coded (color, labels, etc.,) so as to indicate the correct unit and its orientation for replacement.
- i. Units should be removable along a straight or slightly curved line rather than through an angle.
- j. Units should be laid out so that a minimum of place to place movement is required of the operator during checkout.

G. ACCESSIBILITY

1. General Access

- a. Hinged doors or covers with captive quick-opening fasteners should be provided wherever possible.
- b. If a hinged access or quick-opening fastener will not meet stress, pressurization, shielding, or safety requirements, the minimum number of the largest screws consistent with these requirements should be used.
- c. All access covers which are not completely removable should be self-supporting in the open position.
- d. Units should not be placed in recesses, behind, or under stress members, floor boards, seats, hoses, pipes, or other items which are difficult to remove.
- e. If instructions applying to a covered unit are lettered on a hinged door, the lettering should be properly oriented for reading when the door is open.

- f. Sliding, rotating, or hinged units to which rear access is required should be free to open or rotate their full distance and remain in the "open" position without being supported by hand.
- g. Check points, adjustment points, cable end connectors, and labels should be accessible and face the maintenance man where possible.
- h. Bulkheads, brackets, other units, etc., should not interfere with removal or opening of covers of units within which work must be done.
- i. Unless a unit is completely self-checking, provision should be made for checking operation of that unit in the operating condition without the use of special rigs and harnesses.
- j. Where visual access only is required, the following practices should be followed in order of preference:
 - (1) An opening with no cover should be used unless this is likely to degrade system performance.
 - (2) A plastic window should be used if dirt, moisture, or other foreign materials are a problem.
 - (3) A break-resistant glass window should be used if physical wear, heat or contact with solvents will cause optical deterioration.
 - (4) A quick-opening metal cover should be used if glass will not meet stress or other requirements.
- k. Where access for tools, test leads, and service equipment only is required, the following practices should be followed, in order of preference:

- (1) An opening with no cover should be used unless this is likely to degrade system performance.
- (2) A sliding or hinged cap should be used if dirt, moisture, or other foreign materials are a problem.
- (3) A quick-opening cover plate should be used if a cap will not meet stress requirements.

2. Apertures

- a. Openings and work spaces provided for adjusting and handling units should be ample to permit the required activity and where possible to permit adequate view of the components being manipulated. A larger opening must be provided if the operator or maintenance man will be wearing gloves, the degree of enlargement depending on glove thickness.
- b. Units should be located and mounted so that access to them may be achieved without danger to personnel from electrical charge, heat, sharp edges and points, moving parts, chemical contamination, or other sources.

3. Interposition

- a. Removal of any replaceable unit should require opening or removal of a minimum number of covers or panels (preferably one).
- b. Wherever possible, units should be located so that no other equipment must be removed to gain access or remove.
- c. When necessary to place one unit behind another, the unit requiring most frequent access should be most accessible to the user.
- d. Access to units maintained by one operator should not require removal of equipment maintained by a second operator, when such

equipment is of a critical nature, the maintenance of which requires highly specialized skills.

H. CONDUCTORS, CONNECTORS, AND FASTENERS

1. Conductors

- a. Conductors should be bound into cables and held by means of lacing twine or other acceptable means. Long conductors or cables, internal to equipment, should be secured to the chassis by cable clamps.
- b. Cables should be long enough that each functioning unit can be checked in a convenient place. (Extension cables should be provided where this is not feasible).
- c. If it is necessary to route cables and wires through holes in metal partitions, they should be protected from mechanical damage by grommets or other acceptable means. Routing of electrical cables below fluid lines or near high temperature sources should be avoided.
- d. Cables should be routed so that:
 - (1) They cannot be pinched by doors, lids, etc.
 - (2) They cannot be walked on or used for handholds.
 - (3) They are accessible for inspection and repair.
 - (4) They need not be bent or twisted sharply or repeatedly.
 - (5) Cabinet input and output cables, with the exception of test cables, should not terminate on the control-display surfaces of cabinets.
 - (6) If test cables terminate on control and display panels, the test receptacles should be so located that the associated cables will not interfere with controls and displays.

- e. Cables containing individually insulated conductors with a common sheath should be coded as specified in ARDCM 80-5.

2. Connectors

- a. Plugs requiring no more than one turn or other quick disconnect plugs should be used whenever feasible.
- b. Connectors should be located far enough apart that they can be grasped firmly for connection and disconnection. Space required will depend upon the size and shape of the plug.
- c. The rear of plug connectors should be accessible for test and service, except where potting, sealing, or other considerations preclude this.
- d. Plugs or receptacles should be provided with alignment pins or other alignment devices. Aligning pins on plugs should project beyond the electrical pins.
- e. Where a reasonable possibility exists for unintentional interchange of connectors, plugs will be so designed that it is impossible to insert the wrong plug in a receptacle.
- f. Plugs or receptacles should be arranged so that the alignment pins are oriented in the same direction throughout the system.
- g. Connecting plugs and receptacles should be identified by color or shape or other acceptable means.
- h. Plugs and receptacles should have painted stripes, arrows, or other indications to show the position of aligning pins for proper insertion.
- i. The system should be designed so that all "hot" contacts are socket contacts.

3. Fasteners and Mounting Bolts

- a. Maximum use should be made of tongue-and-slot-catches to minimize the number of fasteners required.
- b. The number and diversity of fasteners used should be the minimum commensurate with requirements for stress, bonding, etc.
- c. Where feasible, the same size and type of fasteners should be used for all covers and cases.
- d. Captive fasteners should be used where possible.
- e. Screws with different threads should be of different sizes.
- f. If compatible with stress and load considerations, fasteners for mounting assemblies, subassemblies, etc., should fasten or unfasten in a maximum of one complete turn. If bolts are required, the number of turns required to tighten or loosen them should be minimized.
- g. Hand operated fasteners are preferred, those requiring standard hand tools are acceptable, those requiring nonstandard tools should not be used.
- h. Bolts requiring high torque should be provided with external grip heads.
- i. Captive bolts and nuts should be used in situations where the dropping of these small items into the equipment will cause damage or create a difficult removal problem.

J. TEST POINTS

1. Primary (Operational) Test Points - (Used to isolate malfunctions to a removal subassembly).
 - a. Where a unit is not completely self-checking in its operational condition, appropriate test points should be provided.
 - b. Only such primary test points as are necessary to determine that a unit is malfunctioning should be provided.
 - c. Primary test points be so located and coded as to be readily distinguished from secondary test points.
 - d. Where feasible, primary test points should be grouped in a line or matrix reflecting the sequence of tests to be made.
 - e. Primary test points used in adjusting the unit should be located close to the controls and displays also used in the adjustment.
2. Secondary (Maintenance) Test Points - (Used to isolate a malfunctioning detail part within a subassembly after the subassembly has been removed from the component or major assembly).
 - a. Where feasible, and when not in conflict with other requirements, a secondary test point should be supplied at the input and output of each part or throwaway component.
 - b. Sufficient test points should be provided so that it will not be necessary to remove subassemblies from assemblies in trouble-shooting.
 - c. Each test point should be so marked as to be readily identifiable.

K. EQUIPMENT COLORS

1. Shelters and Trailers - (Those shelters and trailers which house equipment and personnel directly associated with operating or maintaining the direct mission of the system).

a. Operational equipment shelters and trailers should have the following color schemes:

- (1) Floors: Color 36440 - Gray, Federal Standard 595.
- (2) Walls: Color 34670 - Green, Federal Standard 595.
- (3) Ceilings: Color 37886 - White, Federal Standard 595.
- (4) Storage Cabinets and equipment racks: Color 24300 - Green, Federal Standard 595.

b. Pipes, conduit, etc., should be painted the same color as the surface to which they are attached.

2. Consoles and Panels

a. Operational equipment consoles and panels should have the following color schemes:

- (1) Console Exterior: Color 24300 - Green, Federal Standard 595.
- (2) Console Interior: Color 2662 - Gray, Federal Standard 595 (Used only where maintenance and trouble-shooting are required within the console).
- (3) Panels: Color 36492 - Gray, Federal Standard 595.
- (4) Panel Lettering: Color 37038 - Black, Federal Standard 595.

L. WORKSPACE CHARACTERISTICS

1. Anthropometry

- a. The location, size, etc., of equipment should be such that the equipment will be easily operated and maintained by at least the 5th to 95th percentile group of the Air Force population. Consideration should be given to possible environmental conditions which may require personal protective encumbrances and make "normal" operation difficult. The following dimensions should make equipment suitable for 90% of the population. It should be noted that these dimensions must be altered to allow for encumbrances.

Minimum overhead height for standing position -	73 inches.
Maximum allowable overhead reach -	76 inches.
Minimum height required for crawling -	31 inches.
Maximum allowable depth of reach -	23 inches.
Minimum dimension for passing body width -	20 inches.
Minimum dimension for passing body thickness -	13 inches

2. Standing Operations

- a. Ideally, visual displays on vertical panels should be mounted in an area no higher than 70 inches and no lower than 40 inches above the standing surface. Precise reading indicators and important controls should be placed in an area no higher than 64 inches and no lower than 48 inches above the standing surface.
- b. Insofar as possible, controls should be mounted on vertical panels in an area no higher than 70 inches and no lower than 30 inches above the standing surface. The preferred area for precision controls or those operated frequently is between 40 and 55 inches from the standing surface.

3. Seated Operations

- a. When continuous monitoring is required of a seated operator, controls and displays should be mounted on a sloped console surface.

- b. For normal seated operations, the slope of the control-display panel surface should begin at 30 inches from the floor with the over-all console height not exceeding 48 inches. (This will allow the operator's direct line of sight to extend beyond the console).
- c. If the operator's direct line of sight is not required to extend beyond the console, the over-all console height may extend to, but not exceed, 65 inches from the floor. In such situations the upper panel surface should be inclined from the vertical toward the operator.
- d. Arm rests should be provided at all consoles. These rests should either be a part of the console or a part of the operator's chair.
- e. Console arm supports should provide at least 8 inches and preferably 12 inches of resting surface projecting horizontally across the front of the console.
- f. Arm rests integral with the operator's chair should be a minimum of 2 inches wide by 10 inches long.
- g. If the operator must record data, a writing surface 12 inches in depth is recommended.
- h. Knee and foot room beneath the panel surfaces should be provided. The minimum dimensions are: 25 inches high by 20 inches wide by 18 inches deep.
- i. All cabinets, consoles, and work surfaces requiring that an operator stand or sit in close proximity to their front surfaces should contain a kick space 4 inches deep by 4 inches high at the base.
- j. Handles on cabinets and consoles should be recessed when practical to eliminate projections on the cabinet surfaces.

- k. Sufficient room to accommodate the hand should be provided in the grasping of all handles.

4. Work Surfaces

- a. Work benches and other work surfaces provided for standing operations should be 36 inches above the floor.
- b. Desk tops, writing tables, and other work surfaces provided for seated operation should be 30 inches above the floor.
- c. Convenient work surfaces to support job instruction manuals, worksheets, etc., should be provided where necessary for standing operators of control-display panels.

M. HAZARDS AND SAFETY

1. General Safety Considerations - (Representative items).

- a. It should be insured that conspicuous placards are mounted adjacent to high voltage, extremely cold, very hot, etc., equipment.
- b. Operations of switches or controls which initiate hazardous operations, such as ignition, crane moving, etc., should require the prior operation of a related or locking control. Where practicable, the critical position of such controls should activate a warning device in the affected area.
- c. A hazard alerting device should be provided to warn personnel of impending or existing hazards (i.e., fire, presence of combustible or asphyxiating gas, radiation, etc.).
- d. Guards should be provided on all moving parts of machinery and transmission equipment, including pulleys, belts, gears, and blades, etc., in which personnel may become injured or entangled.

- e. Self-locking or other foolproof devices should be incorporated on elevating stands and work platforms to prevent accidental or inadvertent collapse.
- f. Some form of anchor or outriggers should be employed on stands with high centers of gravity.
- g. When applicable, the center of gravity of equipment should be distinctly marked.
- h. Handrails should be provided on platforms, stairs, and around floor openings or wherever personnel may fall from elevation.
- i. A safety bar or chain should be attached across stair or step openings on a platform to prevent falling.
- j. Automatic shut-off devices should be provided on fuel service equipment to prevent overflow and spillage.
- k. Portable hand-operated fire extinguishers should be provided in areas where fire hazards exist or may be created.
- l. All emergency doors and exits should be constructed so that they are readily accessible, unobstructed and quick opening. Design should be such that the door or hatch can be opened by a single motion of hand or foot.
- m. Eye baths, showers and other first aid equipment should be readily available in areas where toxic materials are handled.
- n. Provision should be made for rapid neutralization or flushing of harmful materials spilled on equipment or personnel.
- o. Areas of operation or maintenance where special protective clothing, tools, or equipment such as insulated shoes, nonsparking tools, gloves or suits, etc. are necessary should be specifically identified;

such items should be procured along with system hardware.

- p. "No Step" markings should be incorporated where applicable.
- q. The weight capacity should be indicated on stands, hoists, lifts, jacks, and similar weight-bearing equipment to prevent overloading.
- r. Jacking and hoisting points should be conspicuously and unambiguously identified.
- s. Wiring should be routed through plugs and connectors so that removal of a plug or connector does not expose hot leads.
- t. All pipe lines, liquid, gas, steam, etc., should be clearly and unambiguously labeled or coded as to contents, pressure, heat or cold, and any specific hazards.
- u. Adequate illumination should be provided in all areas. Work areas should be illuminated by at least 25 foot candles.
- v. Provision should be made for skid proof flooring and stair or step treads.
- w. Clearance for fingers should be considered in the design of telescoping steps or ladders.

N. SUPPLEMENTARY DOCUMENTS

The following technical reports, publications, and documents, will serve as supplementary information for those contractors who desire source references.

1. Technical Reports

- a. WADC TR 52-204 Handbook of Acoustic Noise Control.
- b. WADC TR 52-321 Anthropometry of Flying Personnel.
- c. WADC TR 54-520 Anthropometry of Working Positions.
- d. WADC TR 56-171 Layout of Workplaces.

- e. WADC TR 56-218 Guide to Design of Electronic Equipment for Maintainability.
- f. WADC TR 56-488 Procedures for Including Human Engineering Factors in the Development of Weapon Systems.

2. Documents

- a. Federal Standard No. 595--Colors.
- b. Air Force Regulations (AFR) 160-3--Hazardous Noise Exposure.

3. Publications

- a. Air Force - Navy Aeronautical Bulletin No. 261--Abbreviations and Contractions, Approved List of.
- b. ARDC Handbook, ARDCM 80-5--Handbook of Instructions for Ground Equipment Designers.
- c. ARDC Handbook, ARDCM 80-6--Handbook of Instructions for Aircraft Ground Support Equipment Designers.

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U.S. Army Aviation Human Research Unit U.S. Continental Army Command P.O. Box 438, Fort Rucker, Ala. Attn: Maj. Arne H. Eliasson	1

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